MARCH, 1938
No. 327
Vol. XLII.

MONTHLY
PRICE
3/6

ROYAL AERONAUTICAL SOCIETY LIBRARY

The Journal of The Royal Aeronautical Society

With which is incorporated The Institution of Aeronautical Engineers

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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Problems of High Speed Flight as Affected by Compressibility - - - - - - - *Lock*

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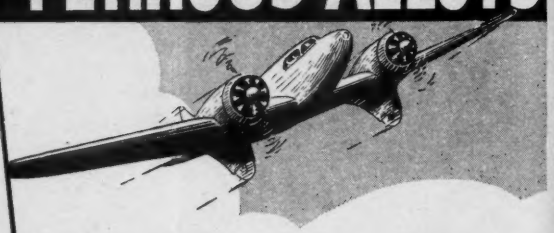

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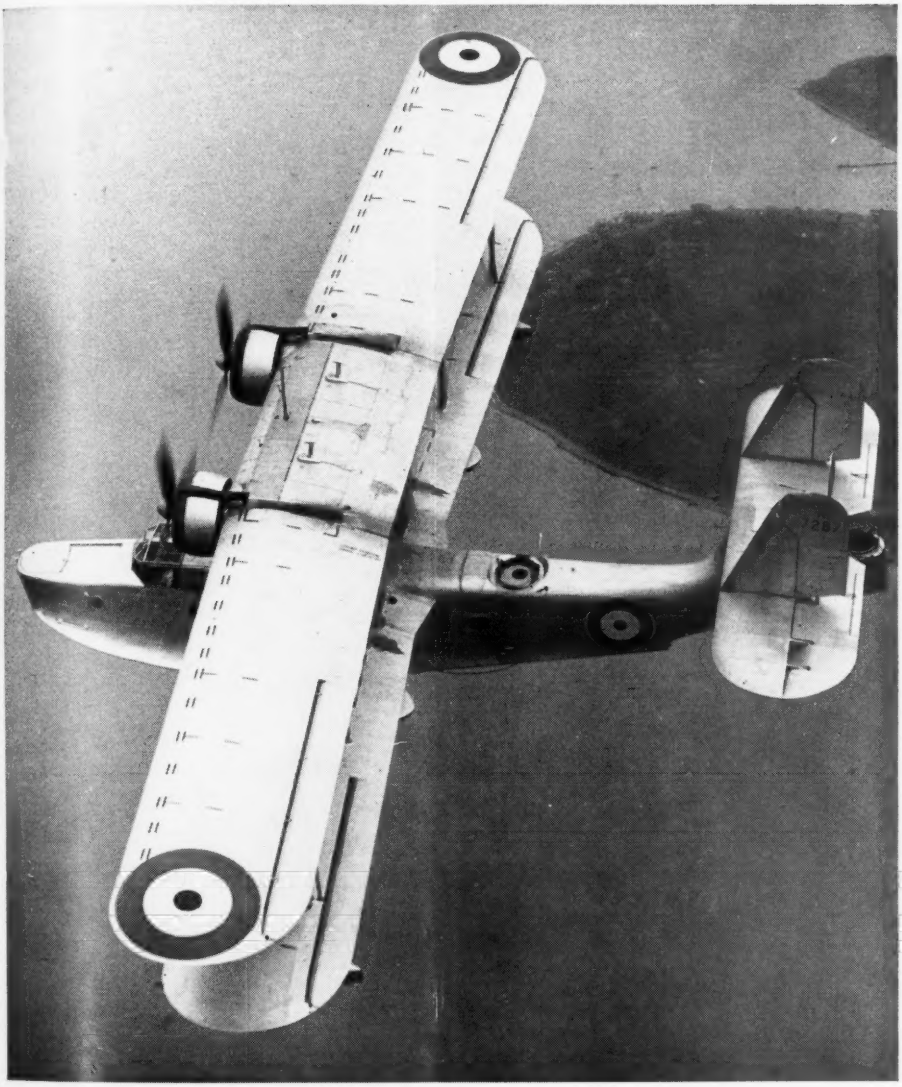

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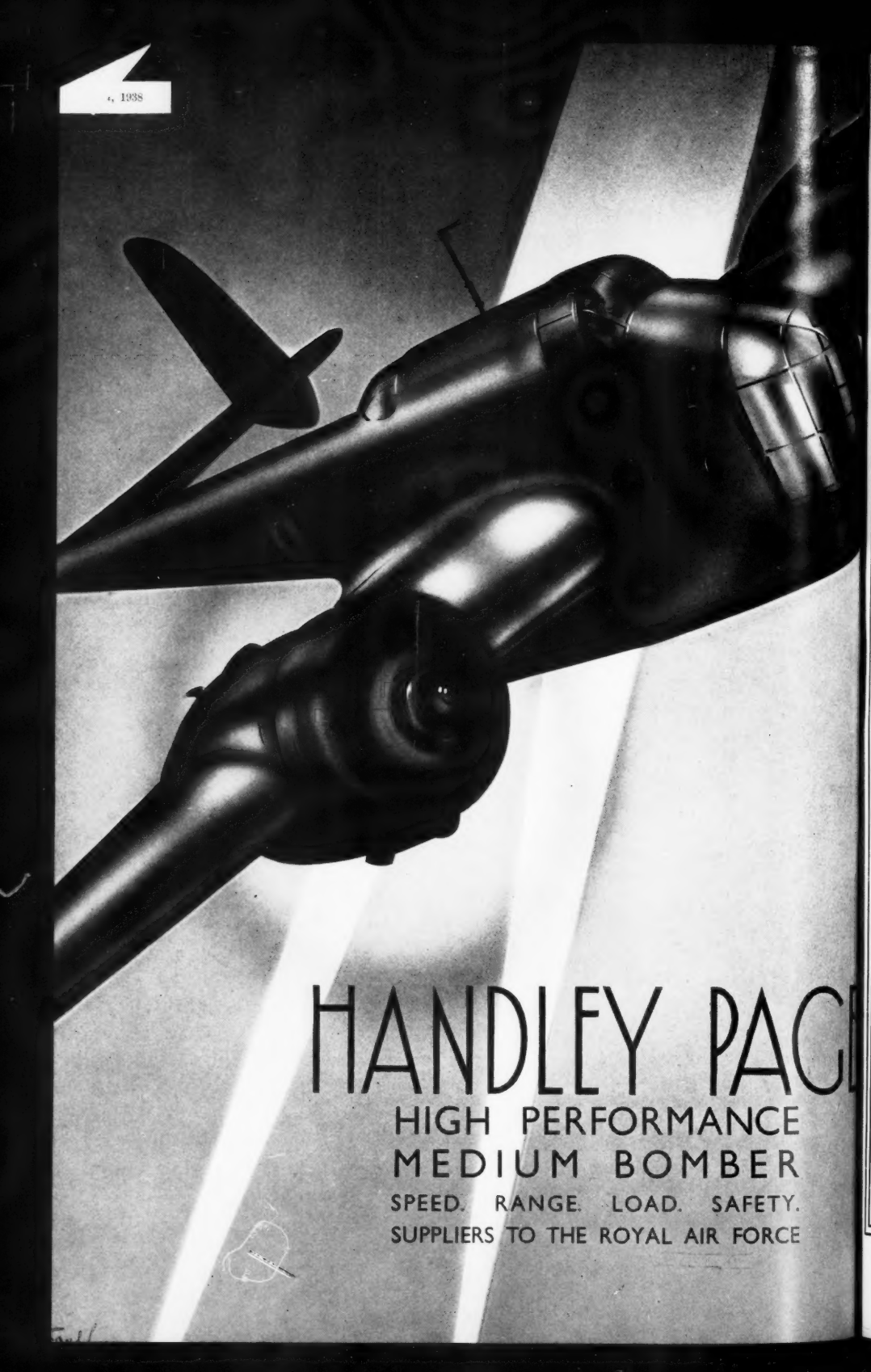
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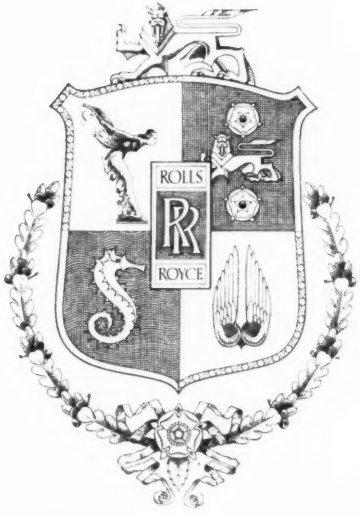

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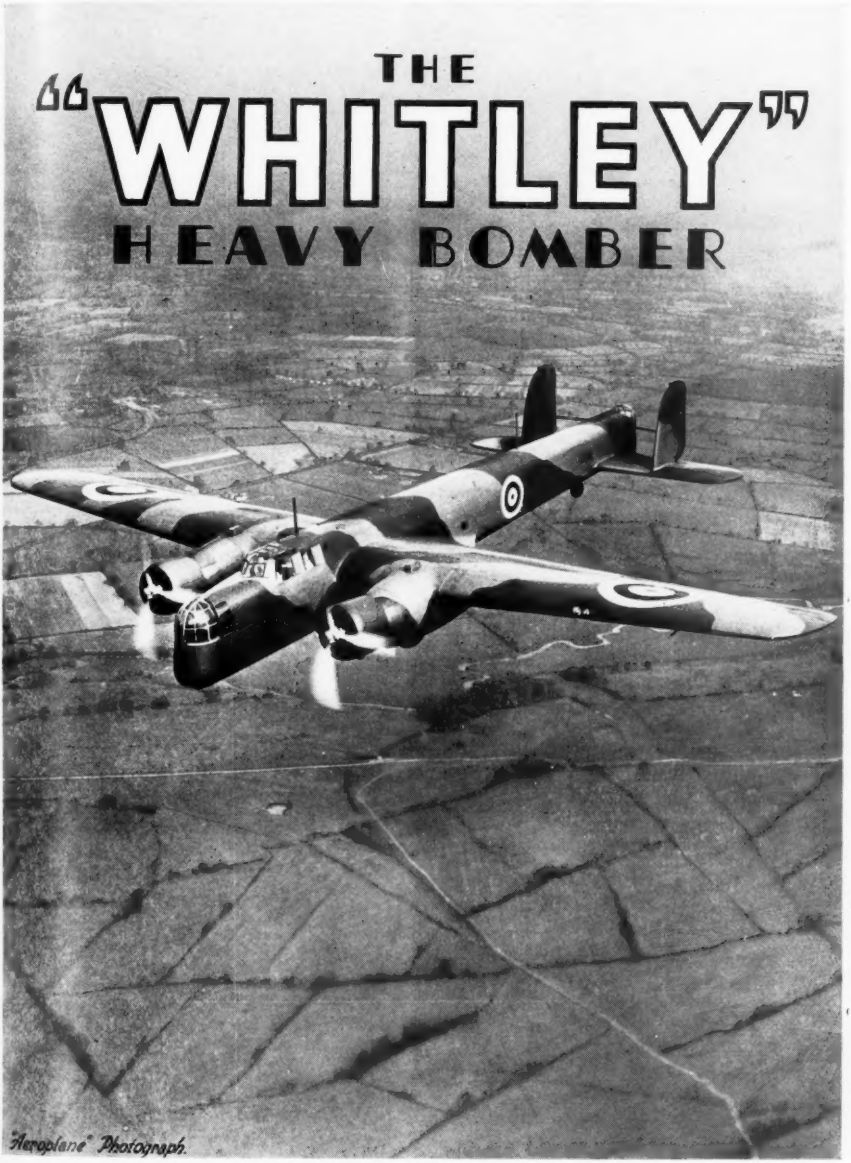

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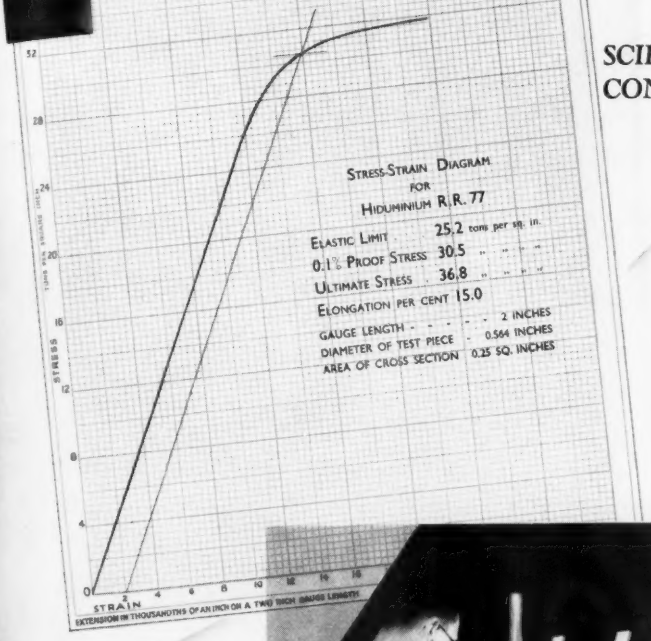
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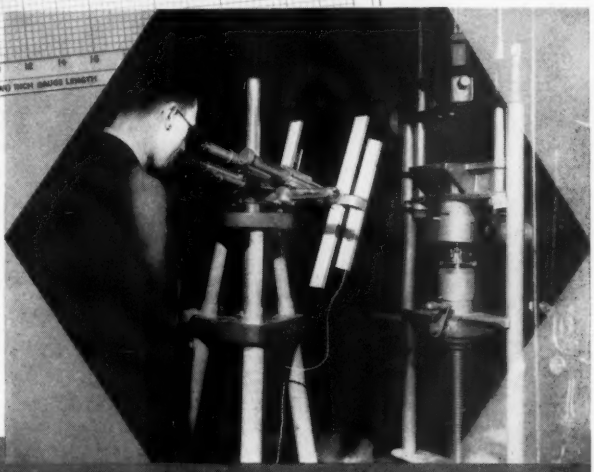

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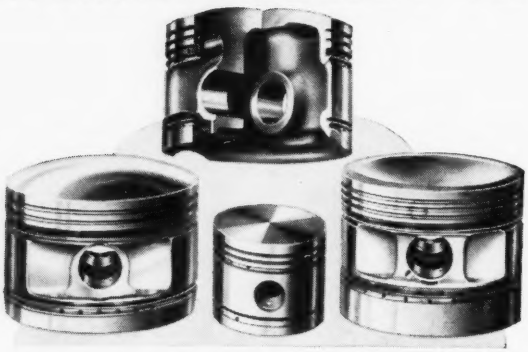

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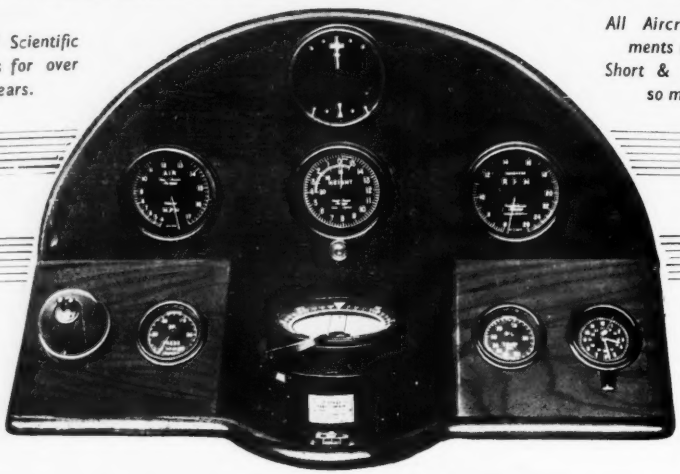

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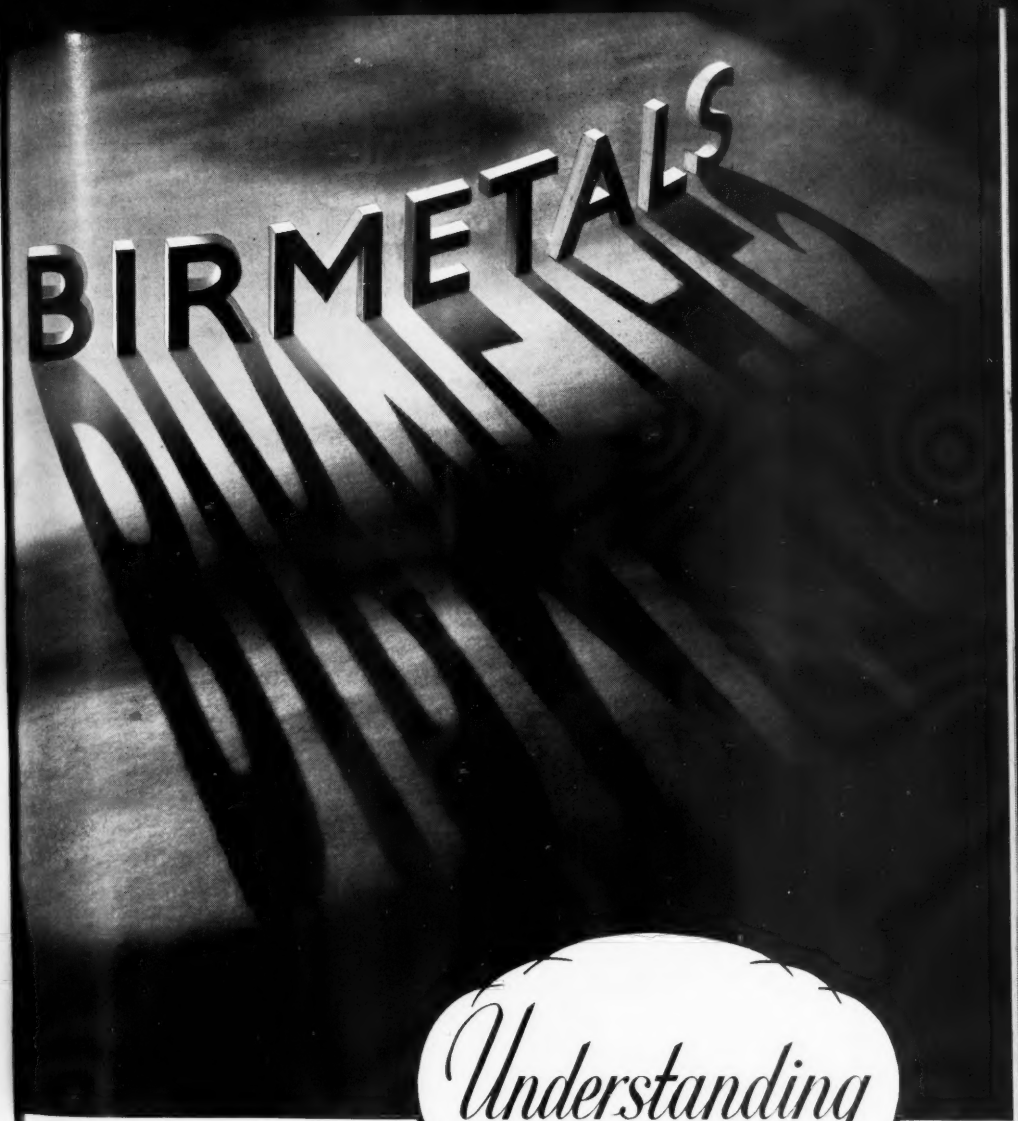

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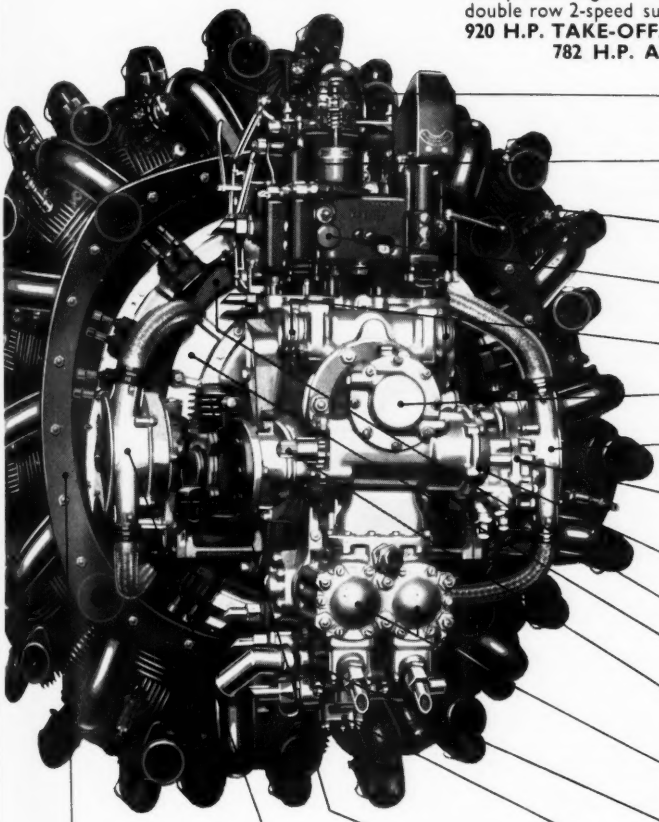

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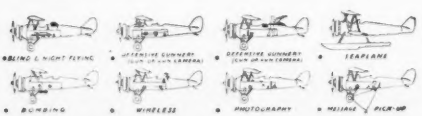

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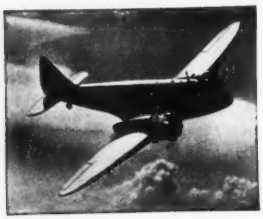

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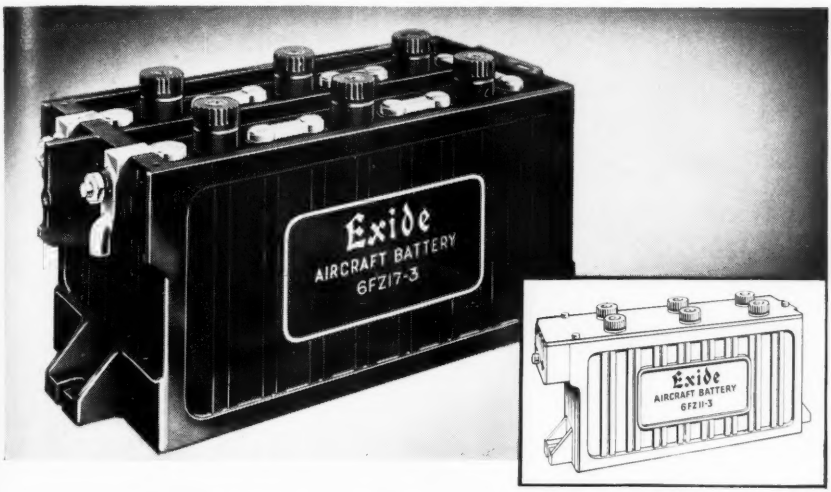

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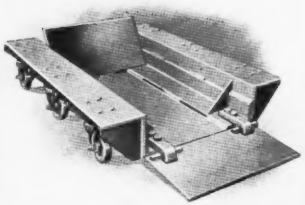

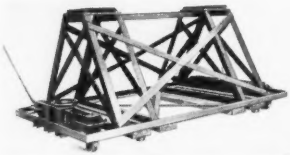

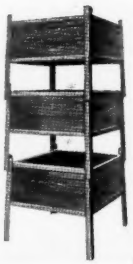

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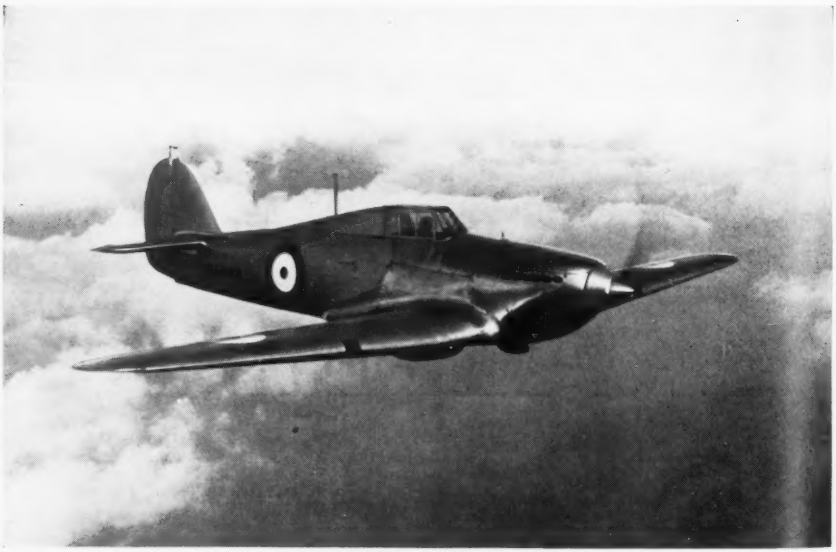

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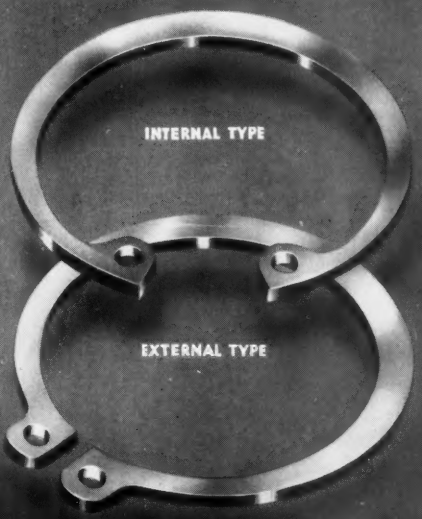

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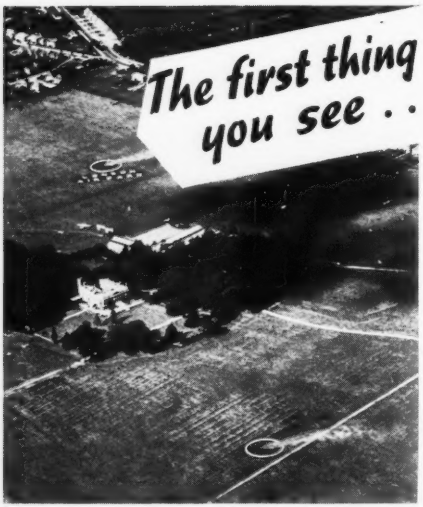

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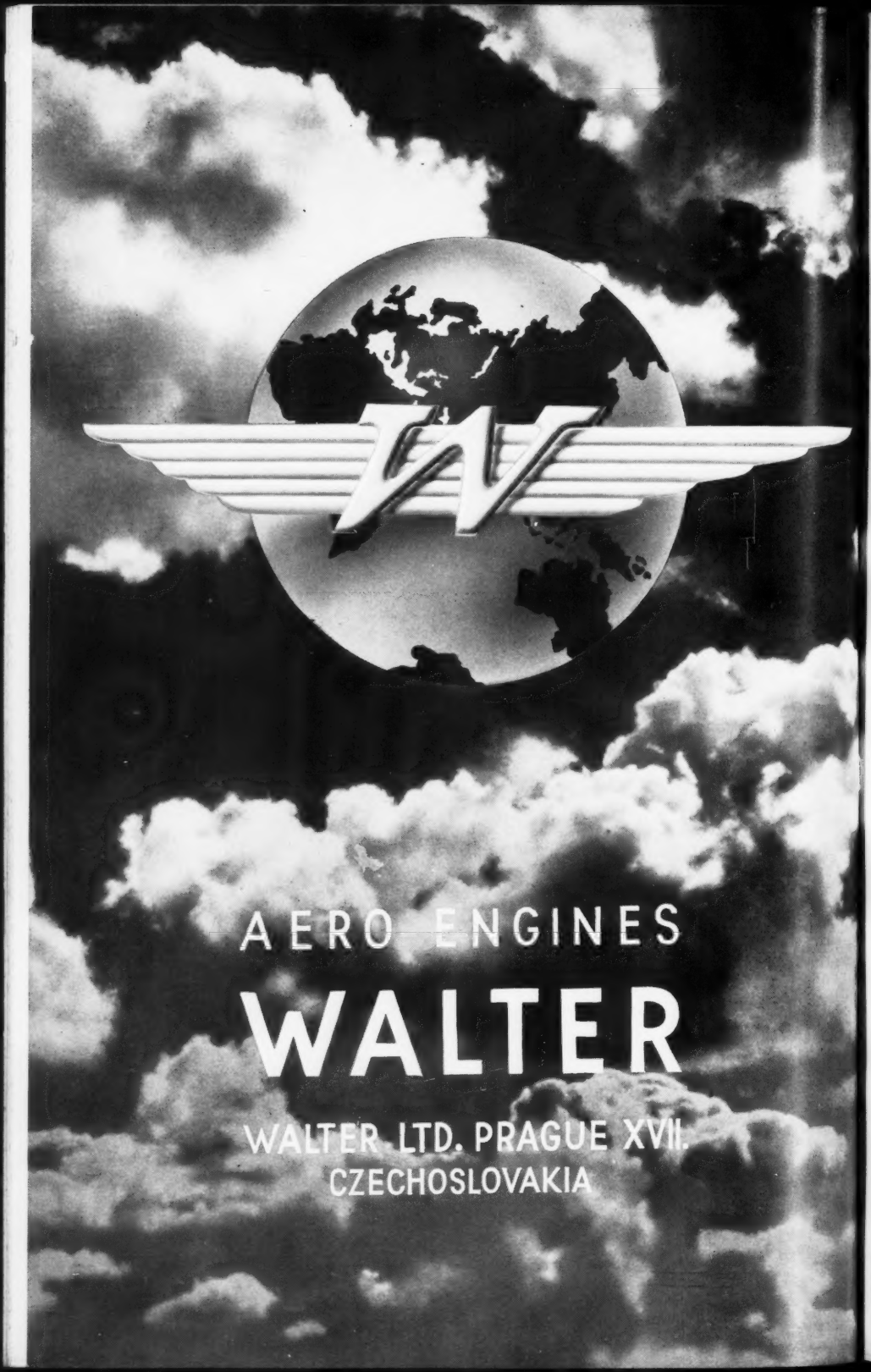
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THE JOURNAL
OF
"THE ROYAL AERONAUTICAL SOCIETY"

With which is Incorporated "The Institution of Aeronautical Engineers."

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the Papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society, unless such is definitely stated to be the case.

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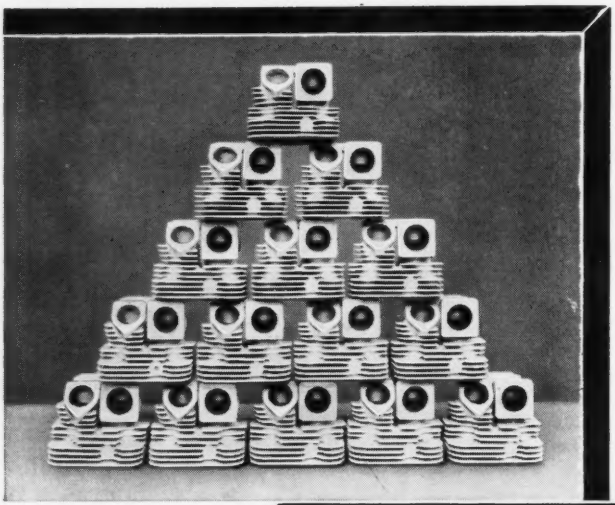

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MONTHLY NOTICES

MARCH, 1938

Annual Ceneral Meeting.

NOTICE IS HEREBY GIVEN THAT THE ANNUAL GENERAL MEETING of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Thursday, March 31st, 1938, at 6.30 p.m., at the Offices of the Society, 7, Albemarle Street, London, W.1.

AGENDA.

1. To read the notice convening the meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society, and the Balance Sheets of Aerial Science Limited, and Aeronautical Trusts Limited, as printed in the Journal of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, for March, 1938.
3. To receive the Report of the scrutineers of the ballot for Council for the years 1938-40.
4. To elect the Auditors for the ensuing year for Aerial Science Limited, and Aeronautical Trusts Limited.
5. To consider any other business.

Election of Council.

Attention is drawn to Rules 68-85 regulating the constitution of the Council, and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Nominations must be received by March 10th, 1938, at the latest.

Council Meeting.

A Meeting of the Council was held on Tuesday, February 8th, 1938, in the Offices of the Society at 7, Albemarle Street, W.1.

Present: Mr. F. Handley Page (Vice-President) in the Chair; Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. W. C. Devereux, Mr. A. H. R. Fedden (Vice-President), Mr. A. Gouge, Mr. A. H. Hall (Vice-President), Professor F. T. Hill, Professor G. T. R. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Lieut.-Col. W. Lockwood Marsh, Lieut.-Col. J. T. C. Moore-

Brabazon (Past-President), Dr. N. A. V. Piercy, Professor A. J. Sutton Pippard, Mr. D. R. Pye (Vice-President), Mr. E. F. Relf, Lord Sempill.

Among the business discussed was the following:—Report of the Finance Committee; Report of the Grading Committee; new premises for the Society; proposed dinners to foreign lecturers; Wilbur Wright Memorial Lecture; letter from the Parliamentary Science Guild; Annual General Meeting.

Election of Members.

The following recommendations of the Grading Committee were approved by the Council at their meeting on February 8th, 1938:—

Fellows.—Walter Brierley (from Associate Fellow), Barnes Neville Wallis.

Associate Fellows.—Edmund Roy Cooper (from Student), Robert William Corbitt, Herbert Jeffree, Maurice Glyn Lloyd-Jones, Robert Pringle, Harold Zettersten (from Companion).

Associate Member.—Erich Carl Albert Backhaus (from Associate), John Burt Flynn (from Associate, Australian Branch).

Associates.—Willian Roy Baird (from Associate Fellow), Percival Lester Barling, A. M. de Hauteville Bell, Ronald Ogilvy Maurice Graham (from Student), Dinabandhu Guha.

Graduates.—Henry Aldin Craw (from Student), Peter Alan Lantsbery Grear (from Student), Geoffrey Patrick Hebden (from Student), David Mellor Jameson, Arthur Oliver Mattocks (from Student), George Wishart Nicholas, Arthur Drummond Williams Pimm (from Companion).

Students.—Hubert John Allwright, David Charles Appleyard, D. S. Bancroft, Robert Pierssene Battey, Charles Kenneth Bonner, Alan Bremner Coates, Mirea M. Conea, Jere Tiffin Farrah, Frank John French, Henry James Suffolk Hall, Alfred Holmes Hammond, Yushan Huang, Peter George Gradwick Knight, Hubert Desmond Leigh, Herbert Edward Le Sueur, Joseph Levine, John Joseph Lindsay, Ernest Henry Nason, George Edward Otter, Angus Rayfield Pitt, William Rieter, Claude Whittard Slatter, Ian Maxwell Strachan, Leo A. Weiss, George Brownlee Young.

Companion.—Miss Frances Mary Buss.

Associate Fellowship and Associate Membership Examinations.

The next examinations will be held in London in May, 1938. Entry forms, obtainable from the Secretary, should be sent in with entrance fees not later than March 31st, 1938. Entries received after that date will not be considered valid.

Wilbur Wright Memorial Lecture.

The 26th Wilbur Wright Memorial Lecture will be given by Dr. H. Gough, M.B.E., F.R.S., M.I.Mech.E., on Thursday, May 26th, 1938. The lecture will be held at the Institution of Mechanical Engineers (by permission of the Council of the Institution), Storey's Gate, St. James's Park, S.W.1. The subject of the lecture will be "Materials for Aircraft Construction."

Lecture Programme.

The following is a complete list of lectures to be read before the Society for the remainder of the present Session.

March 3rd.—Dr.-Ing. W. Pleines, "Riveting Methods in German Aeroplane Construction."

April 7th.—E. G. Richardson, Esq., B.A., D.Sc., Ph.D., " The Manipulation of the Boundary Layer."

April 21st.—Lecture by Professor J. E. Younger, Ph.D., A.F.I.Ae.S., on " High Altitude Flying."

April 28th.—Lecture by Dr. G. E. Bairsto, M.I.E.E., F.Inst.P., on " Factors Controlling the Development of Electrical Ignition on Aero Engines."

May 26th.—Wilbur Wright Memorial Lecture. Dr. H. J. Gough, M.B.E., F.R.S., on " Materials for Aircraft Construction."

Journal Binding.

Arrangements have been made for Members' Journals to be bound at the special price of 4s. 6d. per volume for the current volume and 5s. 6d. for back volumes. Journals should be sent to the Lewes Press Limited, Friars Walk, Lewes, Sussex, and a remittance to the Society. Postage is 9d. for one volume and 1s. 0d. for two volumes.

Acknowledgments.

The Council wish especially to express their grateful thanks to Captain Norman McMillan, M.C., A.F.C., F.R.S.A., A.F.R.Ae.S., for his gift of a considerable number of past issues of the Journal and Reports and Memoranda of the Aeronautical Research Committee. The Council also wish to thank Mr. F. P. Walsh, Associate Fellow, for a complete set of Journals for 1937 and a complete set of the Journal of Scientific Instruments for 1937.

Additions to the Library.

The Fine Structure of Matter, by C. H. Douglas Clark.

Transactions of the Chartered Institute of Patent Agents, Volume LV, Session 1936-37.

Proceedings of the Institution of Mechanical Engineers, Volume 136, June-November, 1936.

The Air Annual of the British Empire, 1938.

International Index to Aeronautical Technical Reports, 1937.

Faraday and His Metallurgical Researches: With Special Reference to Their Bearing on the Development of Alloy Steels, by Sir Robert Hadfield, Bart.

Metallurgy and its Influence on Modern Progress, by Sir Robert Hadfield, Bart.

The Climate of the British Isles, E. G. Bilham.

Northern Lights, by A. S. Eve, C.B.E., D.Sc., F.R.S., Smithsonian Publication No. 3419.

Aerial Photography, by Captain H. K. Baisley, Smithsonian Publication No. 3434.

Extensions of the New Family of Wing Profiles, by R. W. Piper, M.Sc. (from the Philosophical Magazine, Series 7, December, 1937).

Upper Winds Measured at M/Y Imperia, Mirabella Bay, Crete, by J. Durward.

The Rainfall in the Indian Peninsula associated with Cyclonic Storms from the Bay of Bengal during the Post-Monsoon and Early Winter Seasons, by K. P. Ramakrishnan.

Abridgments of Patent Specifications, Nos. 440,001-460,000.

Résumé of Commercial Information, Series 8, No. 3, August-December, 1937 (Part I).

Résumé of Commercial Information, Series 8, No. 3, August-December, 1937 (Part II).

Résumé of Commercial Information, Special Issue, No. 3, 1938.

An Application of the Principle of Superposition to Certain Structural Problems. Professor A. J. Sutton Pippard.

Reports and Memoranda of the Aeronautical Research Committee:—

No. 1787. Tests on a Single Section of R.100 at Cardington, by T. S. D. Collins and Miss L. Chitty.

No. 1788. Estimation of Increase in Lift Due to Slipstream, by R. Smelt and H. Davies.

No. 1794. Lateral Stability of a Single-Engined High Wing Monoplane with Airscrew Running. Yawing Moments Due to Sideslip and Rudder Power, by G. A. McMillan, L. W. Bryant and A. G. Gadd.

Publications Scientifiques et Techniques du Ministere de L'Air:—

No. 114. Chronophotogrammétrie Plane et Stéréoscopique, par C. Chartier.

No. 115. Étude Expérimentale de L'Allumage par Point Chaud dans les Moteurs a Explosion, par Max Serruys.

No. 116. Films Indéformables pour la Photographie Aérienne, par André Charriou and Suzanne Valette.

Technical Reports of the National Advisory Committee for Aeronautics:—

No. 601. Torsion Tests of Tubes, A. H. Stang, Walter Ramberg, and Goldie Back.

No. 602. Wind-Tunnel and Flight Tests of Slot-Lip Ailerons, Joseph A. Shortal.

No. 604. Pressure-Distribution Measurements at large angles of Pitch on Fins of Different Span-Chord Ratio on a 1/40-Scale Model of the U.S. Airship "Akron," J. G. McHugh.

No. 605. Résumé and Analysis of N.A.C.A. Lateral Control Research, F. E. Weick and R. T. Jones.

No. 606. Electrical Thermometers for Aircraft, J. B. Peterson and S. H. J. Womack.

No. 607. Spinning Characteristics of the XN2Y-1 Airplane obtained from the Spinning Balance and compared with results from the Spinning Tunnel and from Flight Tests, M. J. Bamber and R. O. House.

No. 608. Stress Analysis of Beams with Shear Deformation of the Flanges, Paul Kuhn.

No. 610. Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnel, E. N. Jacobs, R. M. Pinkerton, and Harry Greenberg.

No. 611. Wind-Tunnel Investigations of Tapered-Wings with Ordinary Ailerons and Partial-Span Split Flaps, Carl Wenzinger.

Technical Notes of the National Advisory Committee for Aeronautics:—

No. 608. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. I. Basic Loading Condition, Oscar Seidman and A. I. Neidhouse.

No. 609. Considerations Affecting the Additional Weight Required in Mass Balance of Ailerons, W. S. Diehl.

No. 610. Effect of Air-Entry Angle on Performance of a 2-Stroke-Cycle Compression-Ignition Engine by S. L. Earle and F. J. Dutee.

No. 611. The Sonic Altimeter for Aircraft, C. S. Draper.

No. 612. Spinning Characteristics of Wings III- A Rectangular and a Tapered Clark Y Monoplane Wing With Rounded Tips, M. J. Bamber and R. O. House.

No. 613. The Effect of Curvature on the Transition from Laminar to Turbulent Boundary Layer, Milton Clauser and Francis Clauser.

No. 614. Fuselage-Drag Tests in the Variable-Density Wind Tunnel: Streamline Bodies of Revolution, Fineness Ratio of 5, Ira H. Abbott.

No. 615. Motion of the Two-Control Airplane in Rectilinear Flight after Initial Disturbances with Introduction of Controls Following an Exponential Law, Alexander Klemin.

No. 616. The Measurement of Air Speed of Airplanes, F. L. Thompson.

No. 617. Stability of Structural Members under Axial Load, Eugene E. Lundquist.

No. 618. Increasing the Strength of Aluminium-Alloy Columns by Prestressing, M. Holt and E. C. Hartmann.

No. 619. Compression-Ignition Engine Performance at Altitudes and at Various Air Pressures and Temperatures, C. S. Moore and J. H. Collins, Jnr.

No. 620. Energy Loss, Velocity Distribution, and Temperature Distribution for a Baffled Cylinder Model, M. J. Brevoort.

No. 621. Pressure Drop Across Finned Cylinders Enclosed in a Jacket, V. G. Rollin and H. H. Ellerbrook.

Forthcoming Events.

March 3rd.—Lecture before the Society by Dr.-Ing. Wilhelm Pleines on "Riveting Methods in German Aeroplane Construction." Chairman: Mr. A. H. Hall, C.B., C.B.E., M.I.Mech.E., M.Inst.C.E., F.R.Ae.S. (Vice-President).

March 4th—Meeting of the Finance Committee in the Offices of the Society at 5.30 p.m.

March 8th.—Meeting of the Council in the Offices of the Society at 5.30 p.m.

March 31st.—Annual General Meeting in the Offices of the Society at **6.30 p.m.** Light refreshments will be served from 6 o'clock.

April 7th.—Lecture before the Society by Dr. E. G. Richardson, B.A., Ph.D., on "The Manipulation of the Boundary Layer." Chairman: Mr. E. F. Relf, F.R.S., F.R.Ae.S.

The following lecture has been arranged in addition to those mentioned above:—

March 18th.—Lecture before the Institution of Mechanical Engineers, Storey's Gate, S.W.1, by Dr. N. A. V. Piercy, M.Inst.C.E., M.I.Mech.E., M.Cons.E., F.R.Ae.S., on "Aircraft Efficiencies." Members of the Society may apply for tickets of admission and advance copies of the paper direct to the Secretary of the Institution, and are invited to take part in the discussion.

The Society's lectures are held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, S.W.1, at 6.30 p.m. (by permission of the Council of the Institution). Light refreshments are served between 6 and 6.25 p.m.

GRADUATES' AND STUDENTS' SECTION.

March 1st.—Lecture by Mr. H. M. Gallay, B.Sc., M.I.Ae.S., on "Transport Aviation in Canada." Chairman: Mr. C. G. Grey.

March 19th.—Visit to the National Physical Laboratory, 2.30 p.m. Students and Graduates wishing to join the party should send in their names by Monday, March 14th, without fail, giving their nationality, and stating whether they are desirous of taking tea at the National Physical Laboratory at a cost of 1s. 0d. per person.

March 22nd.—Lecture by Mr. H. E. J. Rochefort, Wh.Sch., A.C.G.I., D.I.C., on "Theory and Application of Stressed Skin Construction." Chairman: Mr. H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S.

March 29th.—Lecture by Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S., on "Large Aeroplanes." Chairman: Major C. J. Stewart, O.B.E., M.I.M.E., M.I.A.E., F.R.Ae.S.

April 9th.—Visit to Heston Airport. Meet at Gates at 10 a.m. Graduates and Students wishing to join this party must send in their names by Monday, April 4th.

The Graduates' and Students' Lectures are held in the Library of the Society at 7, Albemarle Street, W.1, at 7.0. Refreshments are supplied from 6—7 before each lecture.

BRANCHES.

Bristol Branch.

March 1st.—Lecture by Dr. T. Swinden on "Steel Development as Related to the Aero Industry." Meetings are held in the Conference Hall at the Bristol Aeroplane Company's Offices, at 7.45 p.m.

Coventry Branch.

March 17th.—Lecture by Captain J. L. Pritchard, Hon. F.R.Ae.S., on "The Ruts of Aviation." Meetings are held at the Liberal Club, Union Street, Coventry, at 8.15 p.m.

Manchester Branch.

March 10th.—Lecture by Dr. R. C. Sutcliffe, of the Meteorological Office, on "Clouds and their Formation, Structure, and Associated Flying Conditions." Lectures are held in the Reynolds' Hall, College of Technology, Sackville Street, Manchester, at 7.30 p.m.

Portsmouth Branch.

March 10th.—Lecture by Sergeant Barnes, on "Air Raid Precautions in Portsmouth."

March 24th.—Lecture by Sir Alan J. Cobham, Hon. F.R.Ae.S., on "Problems and Possibilities of Refuelling in the Air."

Lectures are held at the Airspeed Club, Bowler Avenue, Portsmouth, at 7.30 p.m.

Southampton Branch.

March 2nd.—Lecture by Flight Lieut. H. F. Jenkins, on "De-Icing."

April 6th.—Lecture by Captain F. Entwistle, B.Sc., on "Recent Developments in Meteorology."

Lectures are held at University College, Southampton.

Weybridge Branch.

March 2nd. Lecture by Mr. E. F. Relf, A.R.C.Sc., F.R.S., F.R.Ae.S., on "Aerodynamic Research at the National Physical Laboratory."

April 6th.—Lecture by Mr. I. J. Gerard, M.Sc., A.M.Inst.C.E., A.F.R.Ae.S., on "Stressed Skin Construction."

Lectures are held at 6.15 p.m. in the Senior Staff Canteen, Vickers' Works, Weybridge, by permission of Vickers (Aviation), Limited.

Isle of Wight Branch.

March 8th.—Lecture by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., on "Cowling and Cooling and Air-Cooled Aero Engines."

March 22nd.—Lecture by Captain P. W. Lynche-Blosse on "Air Route and Aerodrome Control."

Lectures are held in the Lecture Room, Columbine Works, Saunders-Roe Limited, East Cowes, at 6.30 p.m.

J. LAURENCE PRITCHARD, *Secretary and Editor*

The 625th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, S.W.1, on Thursday, November 4th, 1937, when a paper by Mr. C. N. H. Lock, *Fellow*, was read, entitled Problems of High Speed Flight as Affected by Compressibility. In the Chair: Mr. A. H. Hall, F.R.Ae.S. (Vice-President).

THE CHAIRMAN: Mr. Lock was a scientific officer at the National Physical Laboratory, and before he went there he had done a great deal of ballistic work. Subsequently he became the leading expert in the country on airscrews. Therefore he was particularly qualified to speak on the high speeds with which his lecture that evening was concerned. Scientists stated that it was possible theoretically to drive a machine at 1,000 miles an hour, but there was a distance between that speed and the speeds at present practicable which it would take a great amount of work to cover. In his written paper Mr. Lock had mentioned nothing about the technique of his measurements at these high speeds.

It appeared to him that these measurements must have been very difficult to make and he hoped that during the discussion some information on this aspect of the work might be given.

PROBLEMS OF HIGH SPEED FLIGHT AS AFFECTED BY COMPRESSIBILITY.

By C. N. H. LOCK, M.A., F.R.Ae.S.

INTRODUCTION.

My lecture deals with the effect of the compressibility of air on bodies moving through it at speeds ranging from the velocity of sound (710 m.p.h. at high altitude) as an upper limit to a lower limit ranging roughly from half to three-quarters the velocity of sound. Somewhere within this range will commence a very rapid increase of the drag coefficient of an aircraft as a result of the formation of local shock waves.

The subject is a novel one and knowledge of the subject is at present scanty. It has only recently attracted the interest of designers, since only now are aeroplanes beginning to reach the speeds at which these effects become important. The fact of being first in the field has this advantage for the lecturer that he may be forgiven for indulging in a certain amount of speculation.

Up till quite recently experiments on the present subject have all been directed towards the improvement of airscrew design and were therefore confined to thin aerofoil sections; the only high speed experiments at present available on thick aerofoil sections are those recently carried out in the new N.P.L. high speed wind tunnel.

I have to thank the Aeronautical Research Committee for permission to include some unpublished data obtained with the N.P.L. high speed wind tunnel. Also the National Advisory Committee for Aeronautics for the original of Fig. 3 and for the data on which Figs. 4 and 5 are based. I should like to thank Mr. Relf for continual help and advice in connection with the work of the high speed tunnel, and also Dr. W. F. Hilton who has carried out most of the experiments.

BRIEF HISTORY OF KNOWLEDGE OF EFFECT OF COMPRESSIBILITY.

When first starting to study the subject of aeronautics we were taught the rather surprising fact that the air might be treated as incompressible. I hope

this evening to elucidate this statement by pointing out the circumstances in which it is not true.

The fact that air is compressible was first forced on the notice of the student of a subject having the forbidding name "exterior ballistics," which merely means the study of the flight of a shell or bullet through air under gravity after it has left the barrel of the gun. It was early discovered that the law of resistance to a bullet behaved in a curious manner as the speed passed through the velocity of sound (Fig. 1). This curve shows a rapid increase of the drag coefficient up to a maximum at a speed somewhat above the velocity of sound, after which the value starts to fall slowly. A point to notice in view of what follows is that the drag coefficient starts to increase at a speed somewhat less than that of sound.

Prof. Boys and others have succeeded in taking photographs of a bullet in flight by means of an electric spark (Fig. 2). This shows the typical "shock wave" or bore which appears when the speed exceeds the speed of sound. The part of the wave at a distance from the shell moves normal to itself with the speed of sound and this fact determines the angle it makes with the direction of motion of the shell (the "Mach angle"). The curved part of the wave in front of the shell is moving faster than the velocity of sound and the part directly in front of the nose must be moving with the velocity of the bullet. It follows that a wave of this type extending outwards to an indefinite distance cannot be formed unless the speed of the bullet exceeds the velocity of sound. For many

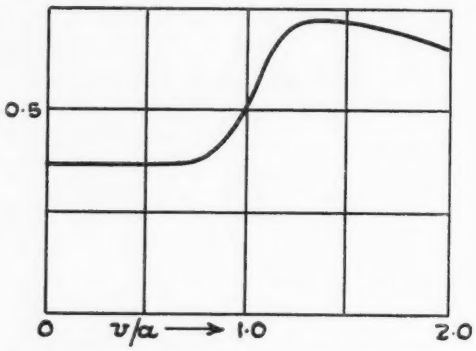


FIG. 1.

years it was somewhat hastily assumed that it was impossible for any sort of shock wave to be formed when a body moves with a speed lower than that of sound.

The theory of the shock wave in one dimension was put on a sound basis by the late Lord Rayleigh following Rankine and Hugoniot (1). In the course of his paper he established a formula for the pressure in an open-ended pitot tube (which has since been verified experimentally by Stanton) on the assumption that a shock wave must be formed across the mouth of the tube when the speed exceeds that of sound. A brief account of the result of this investigation may be given here.

A plane wave or bore of finite amplitude (shock wave) can only maintain itself when the pressure and density both increase on passage through the wave. It is impossible to satisfy all the conditions of flow consistently with the adiabatic relation commonly assumed for compression waves of small amplitude and in

general for all types of flow in a compressible fluid. The explanation of the anomaly is that in the formation of the wave, the transition layer between the regions of different pressure, density and temperature tends to become so thin that the conduction of heat across the boundary becomes important in spite of the low conductivity of air. Calculation shows that a balance is only reached when the transition layer is reduced to a thickness which may be less than a thousandth part of a millimetre. It is evident that the curvature of the wave may then be neglected and the flow treated as one dimensional. It is sufficient for most purposes to assume that the transition is absolutely abrupt and it is then a simple matter to calculate the velocity pressure and density on either side of the wave.

From the point of view of a high speed wind tunnel a shock wave may be considered as a fixed surface at which there is a very rapid change of pressure, density and velocity, the component velocity normal to the surface changing from a velocity u_1 greater than the velocity of sound on the upstream side to a value u_2 less than the velocity of sound on the downstream side. u_1 may also be

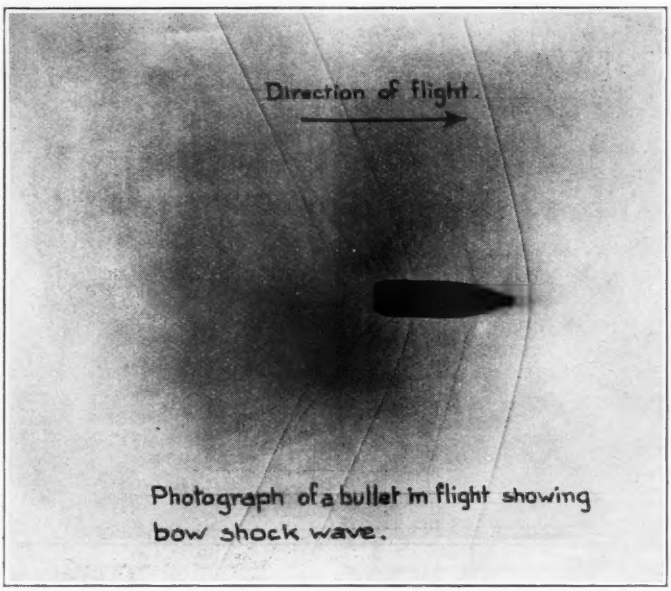


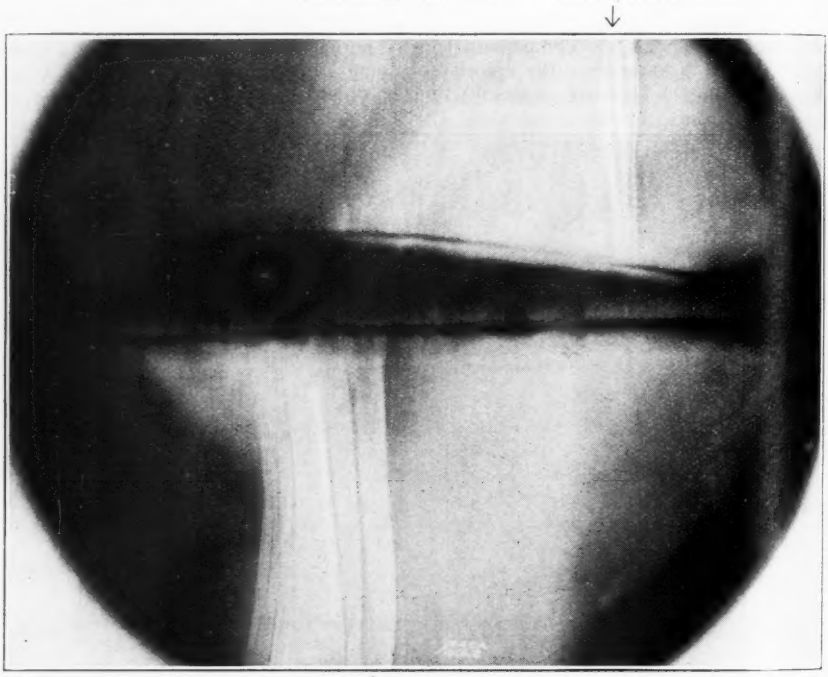
FIG. 2.

considered as the speed of propagation of the shock wave normal to itself into still air. There are then corresponding sudden increases in pressure, density, entropy and temperature, all of which may be calculated if the velocity upstream is known.

We next come to the question of the influence of compressibility on the resistance of a body moving through a perfect fluid. It is well known that there is a unique ideal flow around a symmetrical body such as a sphere or spheroid moving parallel to its axis through a frictionless *incompressible* fluid, such that the velocities and pressures are symmetrical about a plane of symmetry at right angles to the direction of motion and the resistance is therefore absolutely zero. Lord Rayleigh (2) developed a method of successive approximation applicable to the case when the fluid is compressible and showed that each successive

approximation must have the same property of symmetry so that there is no escape from the conclusion that the ideal drag is zero so long as the process of successive approximation is convergent. Lord Rayleigh showed that the process must diverge if the velocity of the body exceeded the velocity of sound, but considered that the process would be convergent and the drag zero at all velocities below the velocity of sound.

The next step in clearing up this question was taken by Taylor and Sharman (3) who put into practice the idea of an electrical analogy to the two-dimensional flow of a compressible fluid. In the simplest application of this method (to an incompressible fluid) electric current flows through water in a two-dimensional



Schlieren flow photograph in American 24″ H.S.W.T. N.A.C.A. 4412; $\alpha = -2°$; $V/V_c = 0.756$.

FIG. 3.

tank with suitably shaped boundaries and the streamlines of an ideal fluid flow are simulated by either the electrical equi-potential lines or the lines of current flow. It appears on comparing the equations of the electrical and hydrodynamical cases, that the depth of the electrical tank may be taken to represent the density of the fluid in the hydrodynamical case. Hence an electrical tank of variable depth (small in comparison with the dimensions of the obstacle) may be used to simulate the effect of the varying density in a *compressible* fluid. In practice the bottom of the tank is constructed of wax and is at first of uniform depth. The electrical streamlines are then observed and a first approximation to the density calculated. The bottom of the tank is then shaped to give a variation of depth corresponding to the calculated density and the process is repeated.

When the speed is low the successive steps converge rapidly to a final result in which the density calculated from the observed streamlines is consistent with the variation of depth of the tank.

At higher speeds the unexpected result was obtained that successive approximations tended to divèrge and it was found that this happened whenever the velocity at any point of the field exceeded the local velocity of sound at some stage of the approximation. The process of successive approximation is similar to, though not identical with, the analytical method employed by Lord Rayleigh; Taylor and Sharman's solution for the circular cylinder started to diverge at a value of V/a of about 0.45. The result strongly suggests that no irrotational adiabatic flow is possible under these conditions.

A suggested solution of the difficulty is that in such cases a limited shock wave is formed entirely confined to the region where the speed exceeds the local velocity of sound. The existence of a shock wave involves a loss of energy which gives an increase of drag of the obstacle.

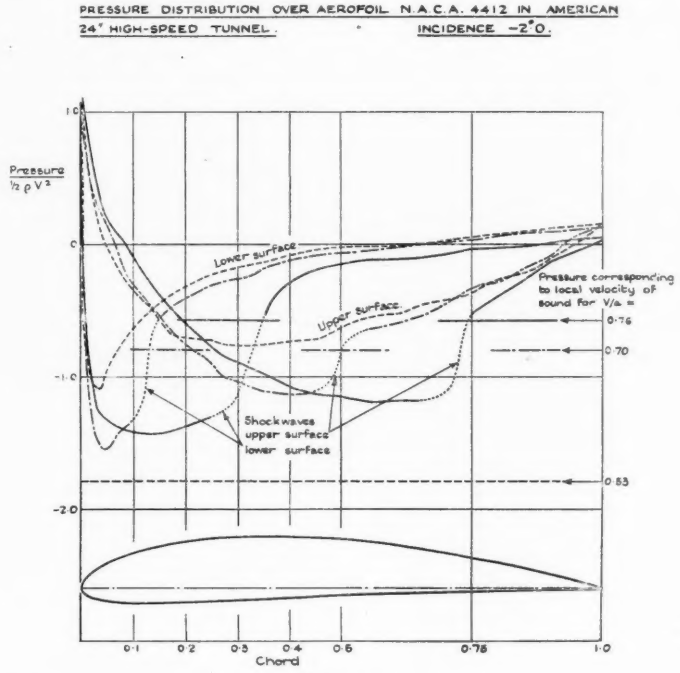


FIG. 4.

Whatever conclusion may be reached as to the nature of the actual flow under these conditions, it seems clear that an ideal irrotational flow with zero drag is not possible if the velocity exceeds the local velocity of sound at any point of the fluid.

The practical conclusion so far is that regions where there is a tendency for the local velocity of sound to be exceeded should be avoided in an aircraft, and this forms the main thesis of the present paper.

PHOTOGRAPHS OF SHOCK WAVES IN THE AMERICAN HIGH SPEED WIND TUNNEL.

Further direct evidence for the existence of a shock wave when the local velocity of sound is exceeded is furnished by photographs taken in the American

24-inch high speed wind tunnel (4) (Fig. 3). These photographs were taken by the Schlieren method and show sudden changes of density in the fluid. The poor definition of the image of the wave does not suggest the degree of sharpness which has been shown to be typical of the true shock wave, but it must be remembered that these photographs are exposed for an appreciable length of time and that the position of the shock wave in the tunnel may well fluctuate rapidly about its mean position.

Simultaneously with the photographs, observations were taken of pressures at a large number of points over the surface of the aerofoil. The pressure curves (Fig. 4) show abrupt changes at the points at which the waves in the photograph meet the aerofoil. On the assumption of adiabatic flow it is possible to calculate the variation of velocity over the surface of the aerofoil up to the point of the discontinuity. It appears that a slight discontinuity is formed as soon as the local velocity exceeds the velocity of sound and becomes more definite as the velocity increases. The negative pressure always falls at the discontinuity by an amount in approximate agreement with the theoretical change across a shock wave.

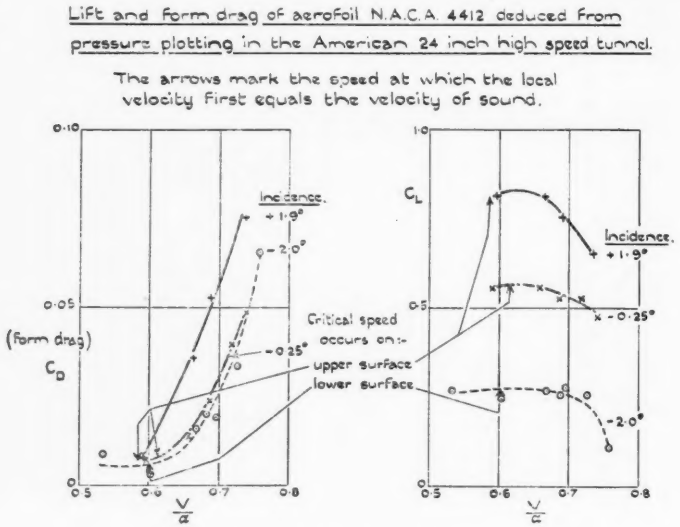


FIG. 5.

An attempt has been made to integrate the observed pressures to obtain lift and form drag (Fig. 5). The lift values are fairly definite and show the tendency to fall at an increasing rate as soon as the critical speed is passed, which will be described in more detail later. The drag coefficients are much less reliable, but they show the expected rapid rise with velocity commencing roughly at the speed at which a pressure discontinuity first commences.

Further evidence of the existence of shock waves at speeds below the velocity of sound is furnished by spark photographs of high tip speed model airscrews taken by Hilton. In a typical example (Fig. 6), photo A shows the airscrews running at a tip speed of 0.83 of the speed of sound and the small wavelets running into the tip show that the wave front is forming; with a slight increase of tip speed these wavelets come together and form a wave, as shown in the second photograph.

EXPERIMENTS WITH HIGH TIP SPEED MODEL AIRSCREWS.

The first reasonably detailed quantitative results on the behaviour of aerofoils at speeds between 0.5 and 1.0 times the velocity of sound were furnished by the analysis of experiments on high tip speed model airscrews by Douglas and Perring (5). In these experiments both thrust and torque grading curves were deduced from the readings of a series of specially designed yaw-meters placed at various radial distances from the centre.

It is outside the scheme of this lecture to deal extensively with the application of these results to airscrew design, which was of course their main object.

FIG. 6A.

FIG. 6B.

The results of the analysis of these experiments is to give reasonably consistent lift and drag coefficient curves of the blade section as functions of incidence and velocity ratio. The experiments were limited to screws of fairly low pitch, on account of the limitation of tunnel speed, and therefore mainly to incidences below the stalling angle. Minor variations with radial distance and model diameter were observed, but in general the results represent the conditions of two-dimensional flow with reasonable accuracy and are confirmed by later experiments in high speed wind tunnels. Typical results are shown in Figs. 7, 8 and 9.

KEY TO AEROFOIL SHAPES REFERRED TO IN FIGS. 7, 8 AND 9.

Blade Section.	Reference Symbol.
R.A.F. type with flat under surface.	
12½ per cent. thick	R 12.5
10 ,, ,, ...	R 10
8 ,, ,, ...	R 8
6 ,, ,, ...	R 6
Joukowski type.	
R.A.F. 27	J 10/0
R.A.F. 31a	J 12.5/2
R.A.F. 28	J 10/2
Biconvex type.	
10 per cent. thick	B 10/2

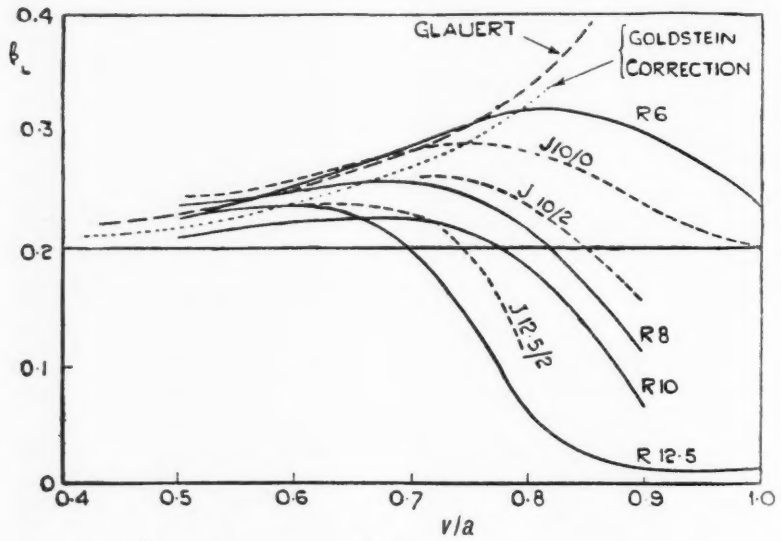


FIG. 7.

Variation of lift coefficient with speed at constant incidence. k_L of aerofoil section at low speed = 0.2. Section at 0.8 of tip radius.

The main trend of variations with velocity ratio for all the aerofoil shapes is as follows:—

The lift tends to increase at first with increasing velocity ratio up to a certain critical speed and then falls rapidly. The initial increase agrees well with a theoretical formula put forward independently by Prandtl and Glauert for the effect of compressibility of the air on the circulation. The formula is

$$C_L = 2\pi a\,(1 - v^2/a^2)^{-\frac{1}{2}}.$$

The beginning of the tendency of the observed lift curve to fall below the theoretical may be assumed to coincide with the breakdown of flow associated with first reaching the velocity of sound on the surface.

Fig. 7 shows that the initial rate of increase is unaffected by change of thickness and shape of section, but that the breakdown occurs earlier the thicker the section, and earlier for the older R.A.F. 6 type of section than for

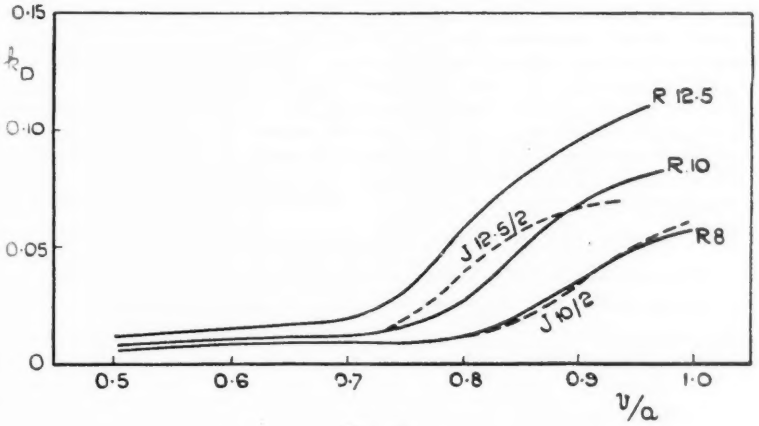


FIG. 8.

Variation of drag coefficient with speed.
k_L=0.2 section at 0.8 of tip radius.

the modern Joukowski type (similar to the Clark Y section). In both variations the earlier breakdown is associated with the higher maximum velocity on the surface for a given lift coefficient and tip speed.

The drag coefficient remains reasonably constant up to a speed which is generally somewhat above the critical speed for lift and then starts to rise at an increasing rate (Fig. 8). Fig. 9 includes a lenticular shape (formed by two circular arcs) which is shown to be inferior to the Joukowski shape, a point to be reconsidered later.

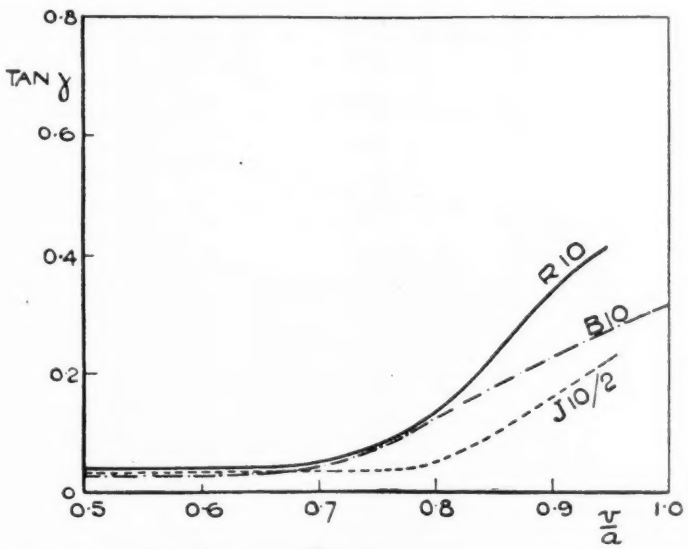


FIG. 9.

Variation of tan γ with speed of section.
k_L=0.2; radius=0.8.

The experiments confirm conclusions given later in the paper, *e.g.*, that the Joukowski section is superior to either the lenticular or the R.A.F. 6 section and that thin sections are superior to thick ones. More recently a method has been developed of deducing lift and drag coefficients from measurements of overall airscrew thrust and torque; the method has been applied to tests of full-scale airscrews in the American propeller research tunnel (6) and (7). The resulting lift and drag coefficients may be considered as applying to a kind of average of the sections at different radii and confirm the experiments on model airscrews. In particular the initial increase of the C_L coefficient (Fig. 10) is consistent with

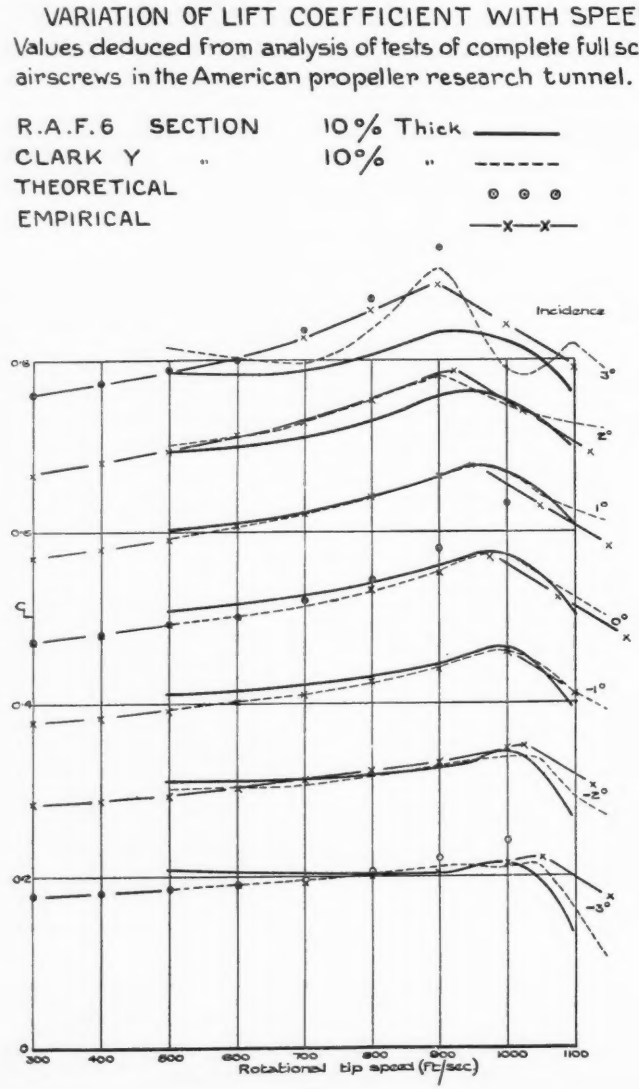


FIG. 10.

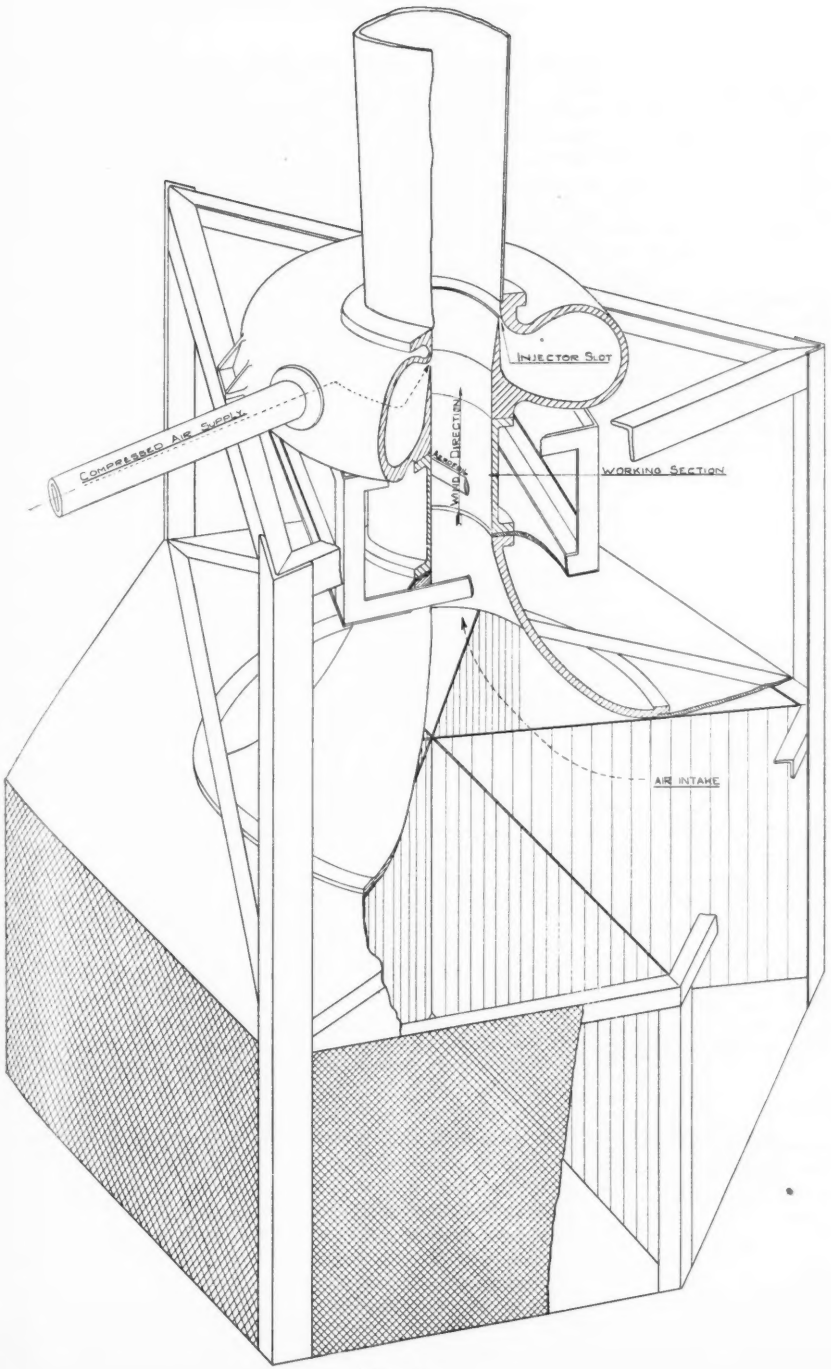


FIG. 11.

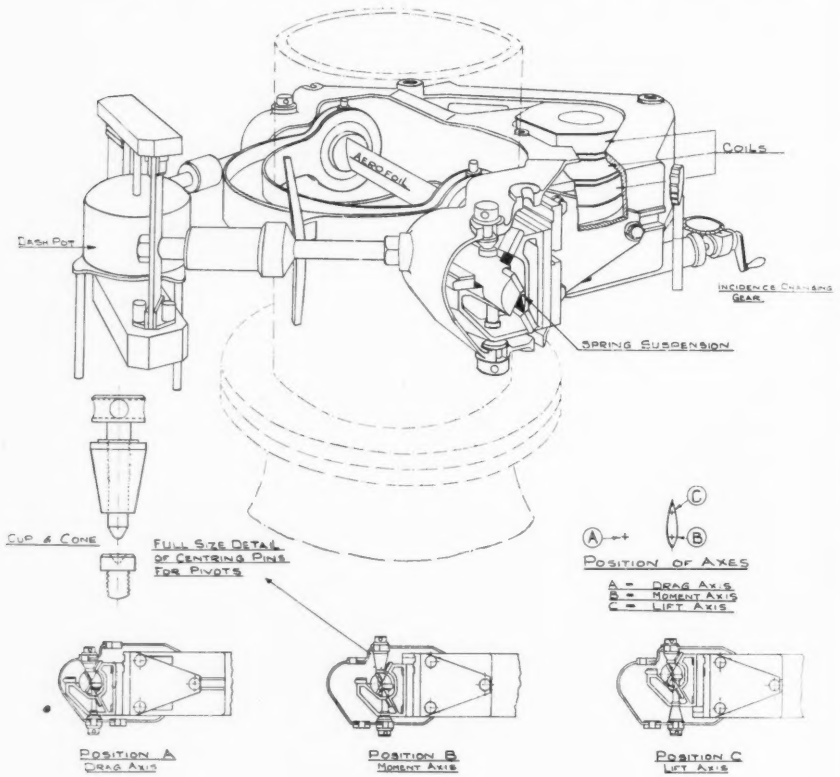
General arrangement of 1 *foot dia. high speed wind tunnel.*

an algebraic formula deduced from Glauert's formula by an integration to allow for variation of effective velocity ratio with radius.

A more convenient method of obtaining data on two-dimensional aerofoils at high compressibility speeds is the high speed wind tunnel which is now an adjunct to the compressed air tunnel at the National Physical Laboratory, being operated by the exhaust pressure air; it is similar in design to the high speed tunnel which has for some years been run from the American Variable Density Tunnel. The detailed design of the N.P.L. tunnel was developed by Stanton and afterwards by Baily and Wood.

Description of N.P.L. High Speed Tunnel.

The tunnel (Fig. 11) consists of a vertical steel tube which may be compared with the old N.P.L. type wind tunnel, but which has a flared entry section, a cylindrical working section of one foot internal diameter, and a long expanding conical exhaust section. The motive power is provided by the escape of high pressure air (from the compressed air tunnel) through the annular injector slot, thus forming a skin of high speed air which sucks air through the working



GENERAL ARRANGEMENT OF ELECTRICAL BALANCE FOR 1FT DIA HIGH SPEED WIND TUNNEL

FIG. 12.

section and mixes with it in the exhaust. In the existing tunnel the mass ratio, that is, the ratio of the total mass of air flowing through the tunnel in a given time to the mass of compressed air discharged through the injector slot is about 4 to 1. The normal working condition of the tunnel requires a pressure in the pipe communicating with the injector slot of about 100lbs. per sq. inch, which is sufficient to produce a velocity equal to the local velocity of sound in a region just below the injector slot, and a velocity ratio of about 0.93 in the unobstructed working section of the tunnel. When a model aerofoil is introduced the speed is reduced by an amount depending on the resistance of the model.

The forces on a model aerofoil are measured on a balance (Fig. 12) (designed by Mr. Fewster of the N.P.L.) of the electrical type similar to that employed in the compressed air tunnel. The ends of the aerofoil pass through clearance holes in the walls of the tunnel and are encastred in a horseshoe-shaped ring half surrounding the tunnel, which is itself connected by ball bearings to a ring frame completely surrounding the tunnel so that the horseshoe frame with the aerofoil can be rotated about the axis of the latter in order to change the incidence. As in the compressed air tunnel balance the ring frame is free to oscillate about an axis which may take any one of three alternative positions, and the moment of the aerodynamic forces about any one of the three axes is balanced against the magnetic attraction of electric coils exactly as in the compressed air tunnel balance. The position of the three axes and the line of action of the force in the coils is shown in the figure. The lift is determined as the difference between the moments about the lift and moment axes, while the drag is the difference between the moment about drag and moment axes. The principal difference between the high speed tunnel and the compressed air tunnel balances lies in the fact that the latter has three separate pairs of pivots of the crossed spring type to any one of which the weight of the balance may be transferred by means of a cam gear, while the former has only a single pair of pivots. By means of devices which are shown in the figure the connection of the earth side of the pivots to earth and of the moving side of the pivots to the balance ring frame can be altered so that the pivots can take up any one of the three required positions while leaving the position of the ring frame relative to earth unaltered.

Up to the present, experiments in the high speed tunnel have been confined mainly to measurements of aerofoil drag by the pitot traverse method and of lift, drag and pitching moment on the balance. The former method has yielded specially interesting results and has not so far as is known been previously attempted in a high speed tunnel.

Experimental Results in N.P.L. High Speed Tunnel.

The pitot traverse method has already been described in some detail in a lecture before this Society and elsewhere (8) in so far as it applies to speeds up to, say, 150 m.p.h., so that it is only necessary here to explain such additional points as arise in the application to compressibility speeds.

At high speeds as at low speeds the result of an experiment is a curve of loss of momentum plotted across a section of the wake of the aerofoil.

Fig. 13 shows a typical pair of curves for a symmetrical aerofoil of moderate thickness (12 per cent.). The figure shows the pronounced broadening of the outer part of the curve as the speed approaches the velocity of sound, with a less important increase of the maximum reading. The resulting increase of area corresponds to a very considerable increase of drag coefficient. The pronounced sideways extension of the curves beyond 0.05 chords at right angles to the aerofoil is strongly suggestive of the formation of a shock wave as shown in the American photographs, but the pitot traverse results cannot by themselves be considered conclusive proof of the existence of a shock wave since a similar effect could conceivably be produced by an extreme thickening of the boundary layer. The transition between the inner and outer parts of the curve becomes

more abrupt when the traverse passes close behind the trailing edge of the aerofoil. Similar curves for a thicker aerofoil (20 per cent. thick, Fig. 14) show a less abrupt transition from the central part of the curve which certainly represents boundary layer losses, to the outer part which may be due to the shock wave.

PITOT TRAVERSE IN WAKE OF AEROFOIL N.A.C.A.0012. (12 PER CENT THICK SYMMETRICAL)
AT 0° INCIDENCE HIGH AND LOW SPEED.

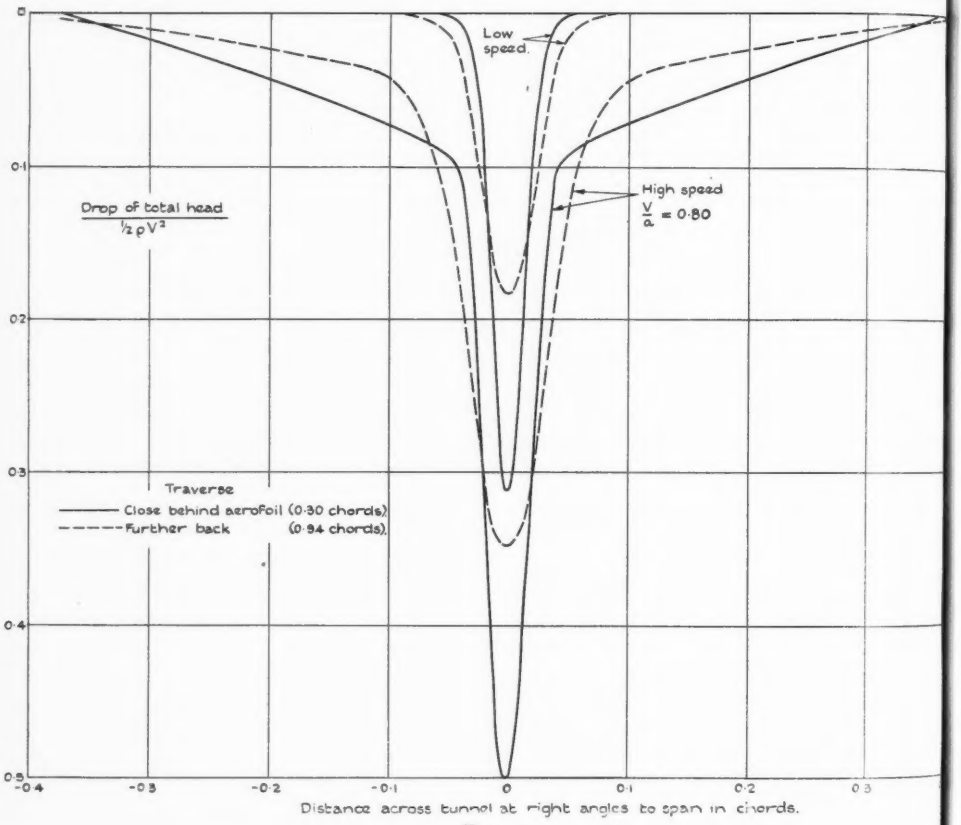


FIG. 13.

The next figure (15) shows more definitely the state of things which we assume to exist. It shows the shock wave (attached to the aerofoil) at which there is a sudden drop of velocity from above to below the local velocity of sound and which forms the rear boundary of the region where the velocity exceeds the local velocity of sound. A sudden change of total head as well as velocity occurs at the wave; for a streamline at some distance from the aerofoil beyond the limits of the turbulent wake it is theoretically possible to calculate from the observed total head drop and static pressure in the wake only, the actual values of velocity,

Pitot traverse in wake of aerofoil N.A.C.A. 0020 (20 per cent. thick symmetrical) at 0° at various speeds. (0.94 chords behind trailing edge.)

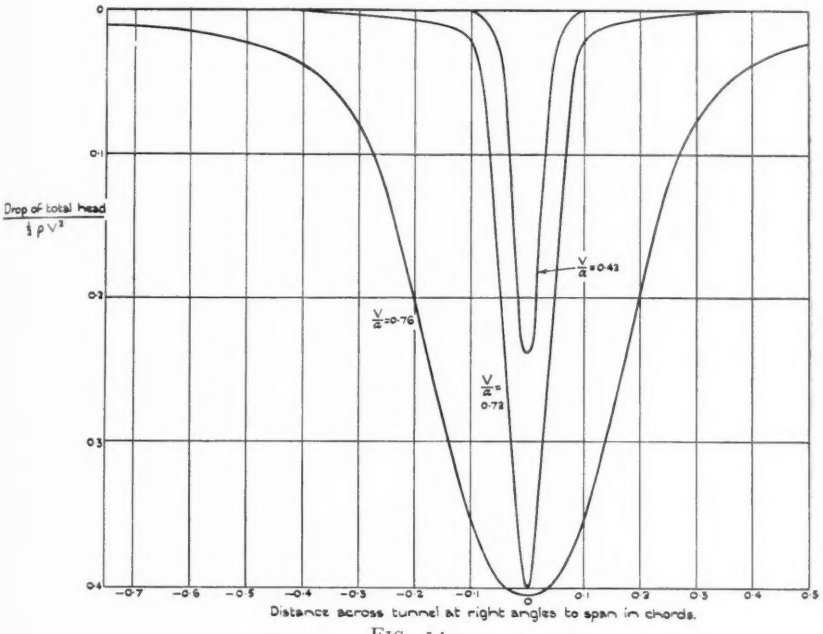


FIG. 14.

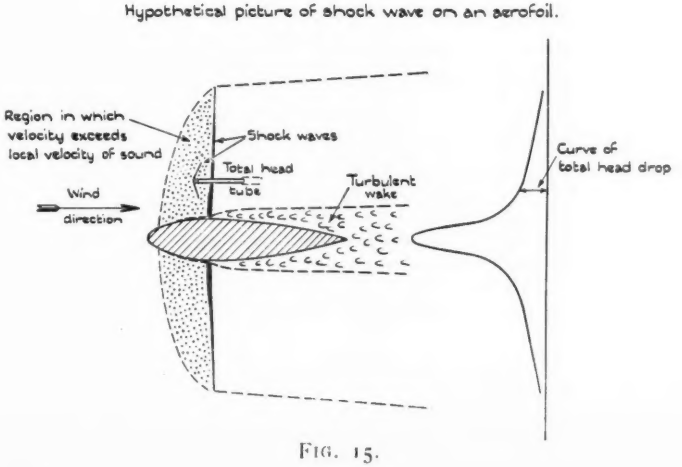

Hypothetical picture of shock wave on an aerofoil.
Region in which velocity exceeds local velocity of sound
Shock waves
Total head tube
Turbulent wake
Wind direction
Curve of total head drop

FIG. 15.

pressure and density on either side of the wave and close to it. (This assumes that the wave surface is approximately normal to the direction of flow at a distance.) It would be of great interest to verify these conclusions experimentally, but so far attempts to do so have not been very successful. This arises partly because a shock wave in a wind tunnel appears to be very critical and to vary in intensity from day to day as a result of slight variations of barometric pressure, and partly because any measuring instruments (pitot or static tubes) will disturb the conditions near the shock wave. Thus although the true total head (pressure

Drag coefficients deduced from pitot traverses in high speed tunnel.

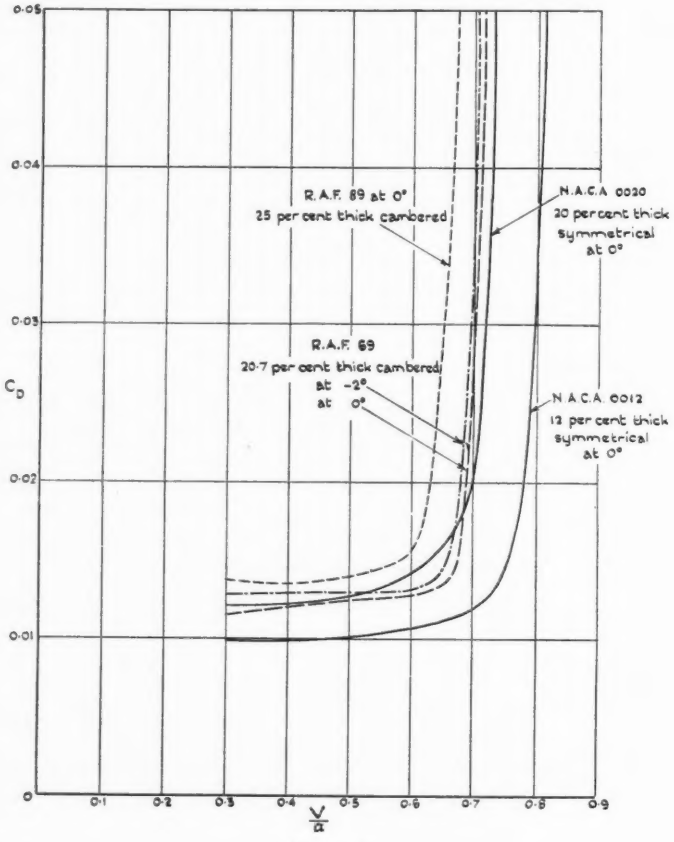


FIG. 16.

of an element of air brought to rest adiabatically) at a point just upstream of the shock wave is normal, a pitot tube placed at this point will form its own shock wave and will read low. The loss of head which in reality occurs abruptly at the shock wave will appear to occur gradually in a pitot tube as it is traversed along the stream, the transition starting at the point at which the local velocity rises to the velocity of sound and ending at the shock wave.

A static tube should theoretically show a discontinuous change of pressure through a shock wave, but it is difficult in practice to design a static tube which will not disturb a shock wave on passing through it.

I shall now touch briefly on points which require special consideration in connection with a pitot traverse made at high speed. There seems to be no doubt that the ordinary momentum relation holds provided that the speed of the aerofoil through the air is less than that of sound and that the velocity is less than the local velocity of sound at all points of the path across stream traversed by the pitot. To determine the momentum loss it is necessary to know the velocity and density, while for traverses which are not very far behind the aerofoil it is necessary to measure the static pressure. The static pressure being known it should be possible to deduce the velocity and density from observations of pressure in a pitot tube and of temperature. The true temperature will not be identical with the temperature measured by a thermocouple of any ordinary shape, but under suitable conditions may be deduced from it. Any uncertainty of temperature must be due to increase of entropy either in passage through the boundary layer or through a shock wave. If the whole increase of entropy were known to be due to a shock wave its amount could be calculated from the total head reading. Preliminary experiments with thermocouples in the N.P.L. high speed tunnel suggest that the error in density produced by ignoring the increase of entropy altogether will not be great enough to affect appreciably the value of drag coefficient in cases of practical importance.

In a practical application of the pitot traverse method the only important difference from standard practice is that the general adiabatic Bernoulli relation must be substituted for the relation appropriate to low speeds when deducing velocity from total head readings. In a particular case worked out from observations in the high speed tunnel it was found that this correction amounted to a reduction of the value of C_D deduced by formulæ appropriate to low speeds by: 1 per cent. at 100 m.p.h., 4 per cent. at 200 m.p.h., 9 per cent. at 300 m.p.h., and so on.

Some typical curves of drag coefficient deduced by graphical integration from pitot traverses are shown in Fig. 16. They show the typical rise in drag coefficient commencing at a critical speed depending on the shape and thickness of the aerofoil. In the case of the thicker sections there appears to be a tendency for the increase to start gradually at a lower speed than that at which the maximum velocity reaches the local velocity of sound. This fact, if it could be sufficiently well established, would be of considerable importance in practice.

Direct measurements of drag with the balance give drag curves which are similar to those obtained by the pitot traverse method, but are higher over the whole range (Fig. 17). The difference is probably due to abnormally high drag at the ends of the aerofoil where it passes through the walls of the tunnel; in this respect the results are similar to those obtained in the American tunnel.

Some preliminary balance measurements have been made of the effect of adding a bulge (of maximum thickness ratio 0.25) and alternatively a typical engine nacelle to the centre of a plain wing (of thickness ratio 0.14). The alteration of the critical speed (at which the drag coefficient starts to increase) by the addition of either the nacelle or the bulge is within the limits of error of experiments; the addition of the bulge certainly does not decrease the critical speed to nearly so low a value as would apply to a uniform wing of thickness equal to the maximum thickness of the bulge.

Balance Measurements in American High Speed Tunnel.

Fig. 18 shows a selection of the results of balance tests of aerofoil sections in the American high speed tunnel (9). It shows the variation of drag coefficient with speed ratio for a series of shapes; and the right and left-hand figures refer to minimum profile drag and drag at $C_L = 0.4$, respectively.

The first pair of figures show the effect of change of thickness between the three symmetrical aerofoils

0012—63
0009—63
0006—63

(12, 9 and 6 per cent. thick). The shock stalling speed decreases with increase of thickness up to the largest thickness tested (12 per cent.) as in the N.P.L. tunnel.

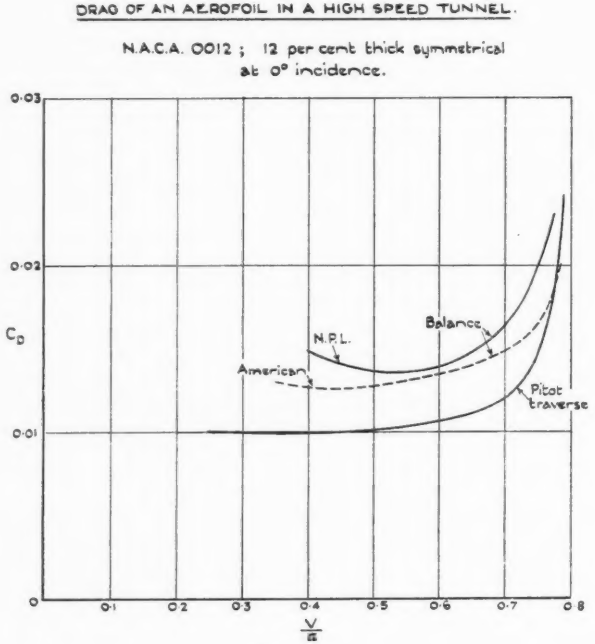


FIG. 17.

The second pair of figures show effect of change of position of maximum ordinate

0009—62
0009—63
0009—64
0009—65
0009—66

(maximum ordinate at 2, 3, 4, 5 and 6 tenths of the chord from the leading edge). These indicate that 4 tenths of the chord from the leading edge is the optimum.

The third pair of figures show the effect of change of leading edge radius

0009—03
0009—33
0009—63
0009—93

(sharp leading edge, leading radius quarter normal, normal, three times normal). These show that all shapes are equally good except the very blunt leading edge.

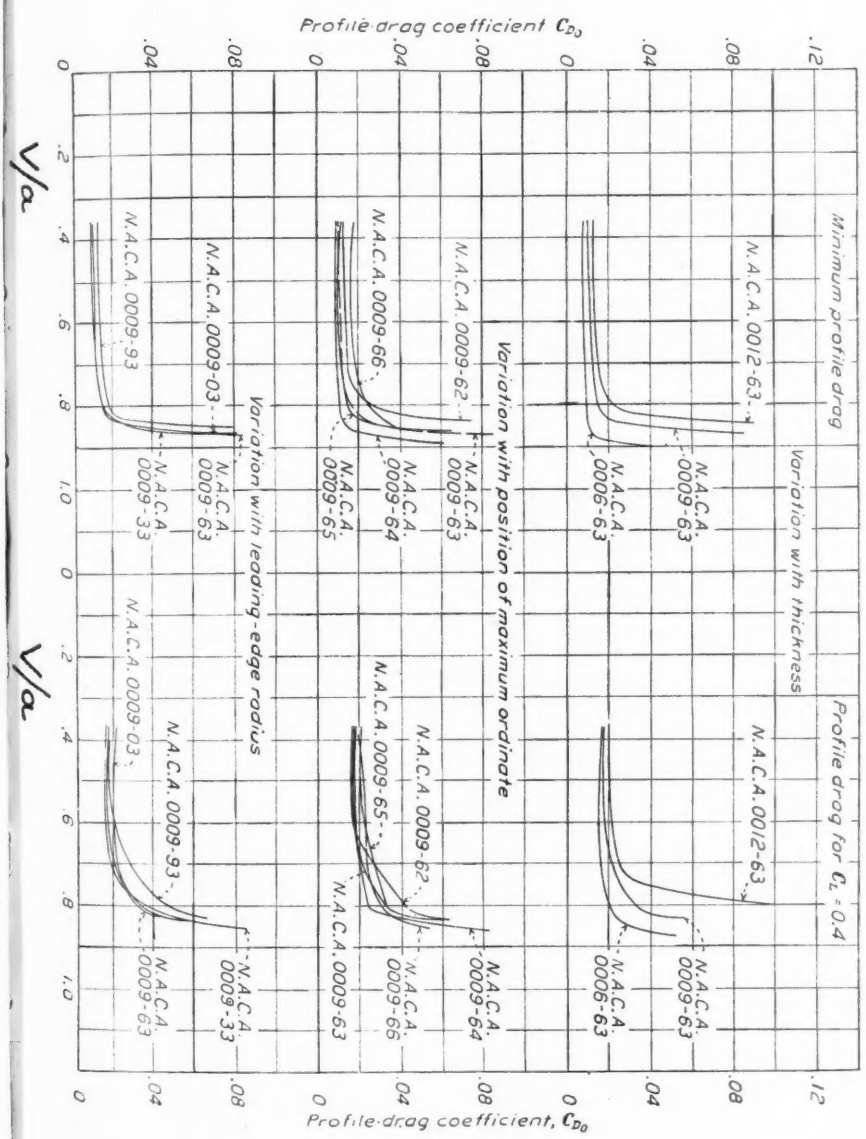


FIG. 18.

Balance measurements of profile drag coefficient in the American high speed wind tunnel.

SOME CONCLUSIONS.

The main conclusion which has emerged from the above discussion of possible effects of compressibility of the air, is that it is very desirable when designing an aircraft to avoid points of high local velocity at which the local velocity of sound may be exceeded. A good deal of information on this point may be deduced by the consideration of certain simple shapes for which the flow can be calculated by elementary methods.

The five shapes shown in the figure (19) have all the same theoretical maximum

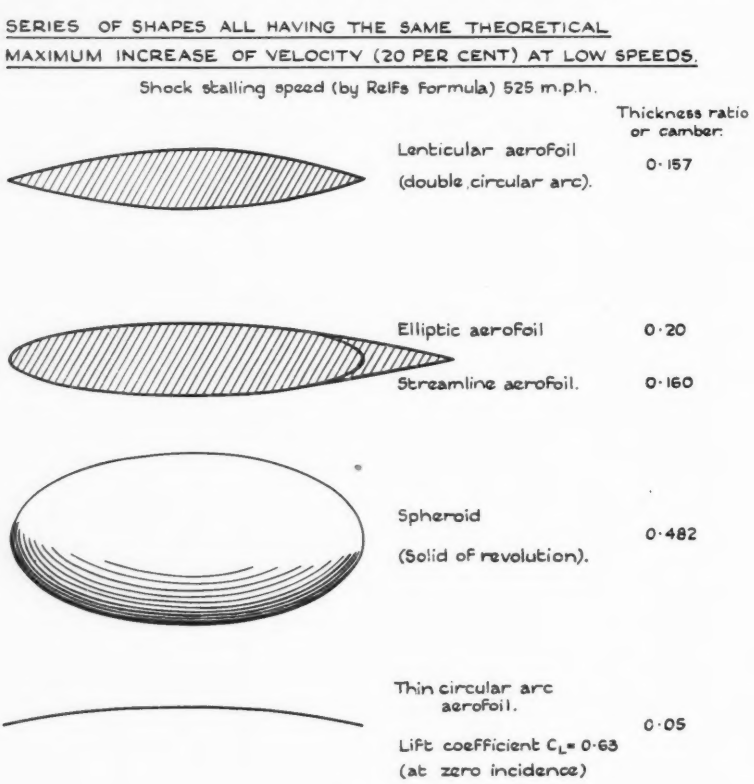


FIG. 19.

local velocity of 1.20 times their forward velocity.* The elliptic cylinder is thicker than the lenticular shape and therefore for a given thickness has a lower maximum velocity than the lenticular cylinder (double circular arc) and therefore presumably a higher shock stalling speed.

This last comparison is of interest because it has been generally supposed that a sharp leading edge is an advantage in avoiding increase of drag due to compressibility, and the lenticular shape was tried on model high tip speed airscrews without success. It is true that when the forward velocity of the whole body exceeds the velocity of sound by a certain margin a shock wave will inevitably be formed in front of the leading edge of the aerofoil and the lenticular form will then very probably have the advantage of reducing to zero the interior part

* The appropriate formulæ are given in the Appendix.

of the shock wave normal to the stream (Fig. 2, bullet photograph). When the general velocity is below the velocity of sound the shock wave tends to form opposite the maximum section and this explains the advantage of the elliptic over the lenticular.

In practice the advantage of the ellipse is offset by the risk of a break away at the rear; this can be prevented by the addition of a tail as shown. The tests in the American high speed tunnel suggest that the maximum thickness should be 0.4 chords from the leading edge, which is nearer the tail than the position for the usual Joukowski section; accordingly, for the purpose of the present report, a streamline shape is obtained by adding to an ellipse a tail of 25 per cent. of the original chord length. Any further blunting of the leading edge as compared with the ellipse will cause the maximum velocity to occur on the shoulder before the maximum thickness is reached, and the shape will therefore be worse than the ellipse for the same thickness.

The elliptic cylinder will next be compared with the three-dimensional body of revolution of similar cross section (the ovary spheroid). The figure shows a comparison between an elliptic cylinder, and a spheroid which gives the same maximum local velocity, and shows that the spheroid can be much fatter than the cylinder for the same shock stalling speed. In practice a streamline tail would also be necessary in the case of the spheroid.

So far the question of lift has not been mentioned, but a certain increase of velocity on the upper surface for a given lift is unavoidable. The minimum increase of velocity apart from considerations of strength (and maximum lift) is probably given by the thin circular arc at zero incidence.

With this shape a lift coefficient (C_L) of 0.63 can be obtained with a velocity increase of 20 per cent. so that a coefficient of 0.1 appropriate to top speed requires an increase of only 3 per cent.

The above comparison is extended in the table (Fig. 20) which gives comparative thickness ratios of streamline and elliptic aerofoils and of spheroids having the same maximum velocity. The table also shows the speeds at which a critical increase of drag would be expected to commence. Those speeds are calculated by a formula due to Mr. Relf* which requires further experimental confirmation. The speeds are likely to be too high rather than too low, but their relative values may be a useful guide.

We may now take a complete aeroplane and consider what are the points at which the maximum velocities are likely to occur and how these are to be reduced. The figure shows a typical fuselage of a high speed aeroplane which approximates to a streamline body of revolution of fineness ratio 0.14. The shape of the forward portion approximates to that of a spheroid of fineness ratio 0.26 so that the critical speed should be as high as 600 miles per hour. This speed will, of course, be reduced by the presence of any irregularities in the outline, but it represents a possible ideal figure.

The C_L at top speed of a high speed machine need not exceed 0.1 so that the limiting speed would still be very high (660 m.p.h.). The most definite limitation would appear to be the necessity for structural strength of the wing. Thus if a thickness of 20 per cent. is inevitable in the cantilever monoplane the limiting speed is reduced to 500 m.p.h. If this figure (20 per cent.) represents the maximum thickness of a tapered wing, however, the limiting speed would be somewhat raised since the tapered wing will evidently approximate slightly towards the three-dimensional form. The ideal shape is an ellipse with streamline tail and with centre line slightly cambered to suit the value of C_L at top speed, and this is in fact the shape commonly used in practice, except that the maximum thickness should be at 0.4 chords from the leading edge.

It might be suggested that since an increase of incidence from the value zero (assumed to correspond to maximum speed) rapidly increases the maximum value

* See Appendix.

of q^2/V^2, the tendency towards a shock stall might increase, but actually a numerical investigation shows that the reduction of V with increase of incidence more than compensates for the increase of (q^2/V^2). Thus when guarding against the shock stall it is unnecessary to consider forward speeds lower than the top speed. It is of course necessary to consider the ordinary stall when designing the wing.

So far the airscrew has been deliberately excluded, but it is evident that it may be useless to design an engine nacelle of such a shape as to avoid a shock wave if shock waves are produced by the airscrew blade roots. Apart from body interference, the air speed over the blade roots of even a very high pitch airscrew will be higher than the forward speed of the machine so that there is considerable risk of the formation of shock waves on the relatively thick blade roots.

An attempt has been made to estimate how far the conclusions as to limiting forward speeds are modified by consideration of the airscrew (Fig. 21). In

ELLIPTIC AEROFOILS, STREAMLINE AEROFOILS AND SPHEROIDS HAVING THE SAME THEORETICAL SHOCK STALLING SPEED.

Fineness ratios			Theoretical maximum velocity ratio.	Theoretical shock stalling speed by Relf's formula; m.p.h. at high altitude.
Symmetrical Streamline aerofoil.	Elliptic aerofoil	Spheroid		
0·25	$0{\cdot}31_2$	0·69	1·31	470
0·20	0·25	$0{\cdot}57_5$	1·25	500
0·15	$0{\cdot}18_7$	0·46	1·19	530
0·10	0·125	0·29	1·12	570
0·05	0·062	0·21	1·06	630

Typical fuselage. Fineness ratio 0·143. Approximate body of revolution. Fineness ratio of equivalent spheroid 0·26. Theoretical shock stalling speed by Relf's formula, 600 m.p.h.

FIG. 20.

order to arrive at the most favourable case the thin-bladed screw used on the 1931 Schneider Cup machine was taken as the prototype for the thickness chord ratio at various radii. The shock stalling speed of various sections was estimated on the basis already described, and is shown by the dotted curve. On the same diagram are shown the actual air speeds at various radii of an airscrew assumed to have a true tip speed of 670 m.p.h. (0.95 times the velocity of sound) for various forward speeds. The sections near the tip of the screw will form a shock wave in all cases. A shock wave at the root reaches a radius of 0.3 for a forward

speed of 500 and rapidly spreads outwards with increasing speed until at a forward speed of 530 m.p.h. the whole screw carries a shock wave. Hence, even if it is assumed that shock waves near the tip do not spoil the drag of a nacelle there will still be a limit of the order of 400 m.p.h. above which shock wave effects at the surface of the body will have to be considered. The following suggestions may be made in this connection :—

As much as possible of the blade roots should be shielded by a spinner.

The exposed portion of the roots should be made as thin as possible.

It may be desirable to make the nose of an engine nacelle of a fairly bluff shape in order to reduce the velocity over the blade roots.

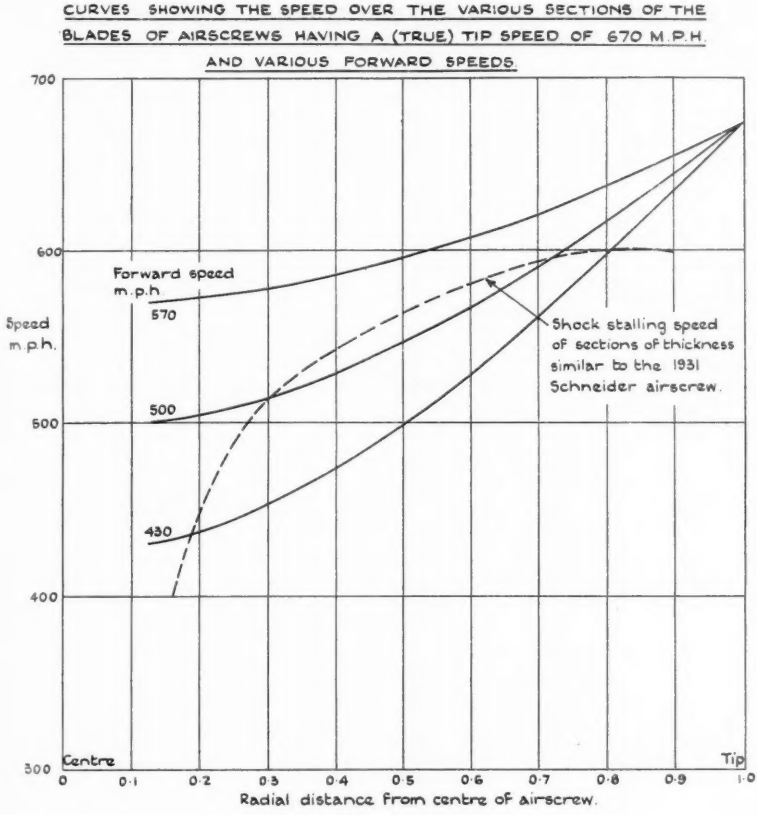


FIG. 21.

It appears that the study of airscrew nacelle interference at high speed will be one of the most difficult of future experimental researches. In the future it is possible that the difficulty will be ultimately overcome by the use of jet or rocket propulsion.

The next point to consider is the cooling of the engine, and here the advantage of ducted cooling becomes evident. There seems to be no reason why the withdrawal of cooling air through suitably designed intakes in the leading edge of wing or fuselage should involve the introduction of additional high velocity spots. The use of the ordinary cowled engine may, however, involve inevitable

high velocity regions over the shoulder of the cowl because of the limitation of distance between the airscrew and the cylinders, and this would be a useful point for future investigation. For a typical cowl the critical speed appears to be about 450 miles per hour. It is evidently difficult to calculate the velocities round any form of air intake, but the following consideration should be a guide. If we take a known shape such as a spheroid and make a hole in the nose and suck air in through it, it is arguable that the maximum velocity will be slightly decreased and the critical speed for drag increased.

Proceeding to the question of minor details it is evident that the avoidance of the compressibility stall forms an additional reason for the avoidance of all

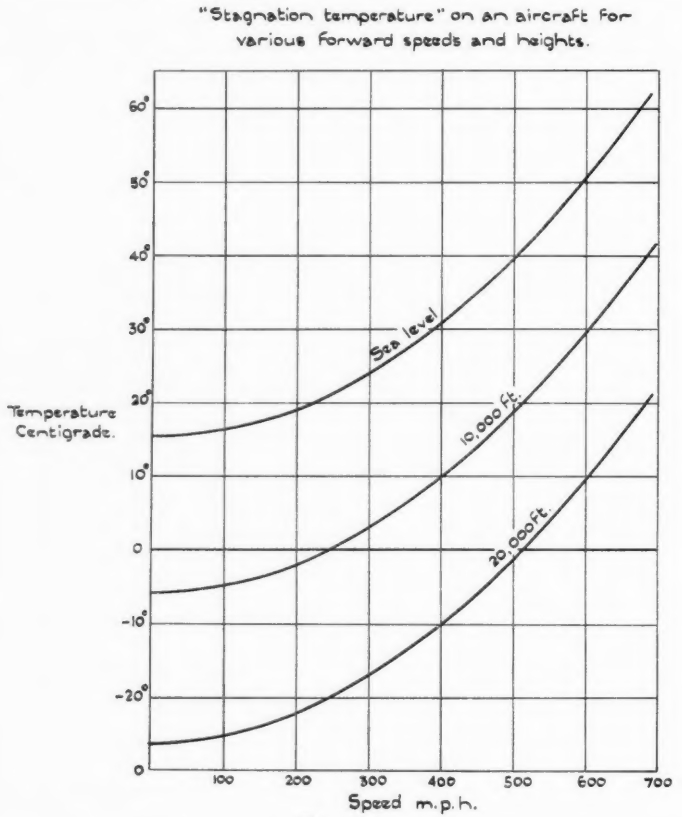


FIG. 22.

casual excrescences and roughnesses as any such will form a potential source of shock wave formation. As an extreme case a bluff obstacle such as a circular cylinder will inevitably form a shock wave at a speed of less than 350 m.p.h.

In discussing the question of engine cooling no mention has so far been made of the inevitable increase of temperature of the cooling air resulting from the high speed of the aircraft. In the case of ducted cooling the velocity of air in contact with the engine is considerably below that of the aircraft and its temperature on reaching the engine will approach that of air brought to rest adiabatically, which may be easily calculated. The results are shown by the curves (Fig. 22) from which it is evident that a considerably greater quantity of cooling air is

necessary on a high high speed aircraft at sea level than would be required if the cooling air were at atmospheric temperature. At high altitude the rise of temperature is avoided but the available mass of air is reduced.

The more definite of the above conclusions are included in the table below, in which various principal features of a machine are placed in a kind of order of merit. The earlier the entry appears in the table the higher the speed at

ORDER OF MERIT OF VARIOUS FEATURES OF AN AIRCRAFT.

		Fineness ratio.	Theoretical shock stalling speed by Relf's Formula; m.p.h. at high altitude.
1.	Thin circular arc (C_L 0.1) ...	—	660
2.	Typical fuselage	—	605
	Streamline body of revolution with	0.14	—
	spheroidal nose	0.26	—
3.	Symmetrical aerofoil sections ...	0.12	550
4.	maximum thickness 0.4	0.20	500
5.	chords behind leading edge ...	0.24	470
6.	Typical engine cowl	—	450
7.	Sphere	—	400
8.	Circular cylinder	—	340

which serious effects of compressibility will commence. It is necessary to repeat that the actual speeds reached depend on a theoretical formula of uncertain accuracy; in the one or two cases in which experimental evidence exists, the speeds given correspond to an increase of drag coefficient of about 50 per cent.

The first item shows that ideally the production of lift at top speed presents no difficulty. If a thin circular arc of suitable camber could be used the critical speed would be as high as 660 m.p.h. Next in order comes a typical well streamlined fuselage. The first factor to cause difficulty is the need for a finite thickness of wing section on account of strength and to allow of a moderate landing speed. Strength requires a thick central section in a tapered cantilever wing, but the limiting speed of a tapered wing will certainly be higher than that of the uniform wing specified here for the same maximum thickness.

The worst item is the typical engine cowling for a radial air-cooled engine. It would appear that the use of ducted cooling should be capable of overcoming this difficulty, but the problem is complicated by the uncertainty as to the effect of the airscrew blade roots.

The sphere and cylinder are added as examples of features to be avoided at all costs.

In general it would appear that the features that are desirable for attaining high compressibility stalling speeds are similar to those tending to low drag at ordinary speeds, but with certain important exceptions. For example, good streamlining will not increase the shock stalling speed of a thick section wing beyond a definite limit depending on the thickness.

APPENDIX.

It has been suggested that it would be useful to quote the actual formula used in obtaining the theoretical shock stalling speed from the calculated maximum velocity over the surface of a body at low speed as in, *e.g.*, Fig. 20.

Let p_L be the minimum pressure over *e.g.*, the upper surface of an aerofoil, corresponding to the maximum local velocity q_L, for a forward speed V_L which is so low that the effect of compressibility may be neglected. These three quantities satisfy the ordinary low speed Bernoulli relation

$$p_L + \tfrac{1}{2}\rho_0 q_L^2 = p_0 + \tfrac{1}{2}\rho_0 V_L^2.$$

Now suppose that at a certain critical forward speed V_c (speed ratio V_c/a_0) the maximum local velocity q_s is equal to the local velocity of sound a, the corresponding pressure being p_s. Then if the adiabatic relation is satisfied

$$(p_s/p_0)^{(\gamma-1/\gamma)} = \{ (\gamma-1)/(\gamma+1) \} (V_c/a_0)^2 + 2/(\gamma+1) \quad . \quad . \quad (1)$$

where $\gamma = 1.40$ and $a_0 = \sqrt{(\gamma p_0/\rho_0)}$. In order to determine V_c/a_0 in terms of low speed data, Mr. Relf suggested making use of the approximate assumption that

$$(p_0 - p_s)/\tfrac{1}{2}\rho_0 V_c^2 = (p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2 \quad . \quad . \quad . \quad (2)$$

Substitution of (2) in (1) gives

$$(p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2 = (2 a_0^2/\gamma V_c^2) \{ 1 - [2/(\gamma+1) + \{ (\gamma-1)/(\gamma+1) \} (V_c/a_0)^2]^{\gamma/(\gamma-1)} \} \quad (3)$$

a relation by which V_c/a_0 may be determined when $p_L/\tfrac{1}{2}\rho_0 V_L^2$ or q_L/V_L are known. It was afterwards discovered that the alternative assumption

$$(p_0 - p_s)/\tfrac{1}{2}\rho_0 V_c^2 = (1 - V_c^2/a_0^2)^{-\frac{1}{2}} \{ (p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2 \}$$

had been used by Eastman N. Jacobs in a paper to the Volta Congress at Rome in October, 1935.* This formula introduces the reducing factor $(1 - V_c^2/a_0^2)^{-\frac{1}{2}}$ which is the same as the Glauert-Prandtl factor for lift given in the lecture. The latter assumption leads to the formula

$$(p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2 = (2 a_0^2/\gamma V_c^2)(1 - V_c^2/a_0^2)^{\frac{1}{2}} \{ 1 - [2/(\gamma+1) + \{ (\gamma-1)/(\gamma+1) \} (V_c/a_0)^2]^{\gamma/(\gamma-1)} \} \quad . \quad . \quad . \quad (4)$$

This formula was used in preference to (3) in the calculations of Figs. 19, 20 and 21, as it appeared to give results in closer agreement with experiment. It is regretted that attribution of (4) to Jacobs was overlooked when delivering the lecture.

The result of equation (4) is given by the following table:—

q_L/V_L	$(p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2$	V_c/a_0	V_c in miles per hour for $a_0 = 710$ m.p.h.
2.087	3.360	0.4	284
1.687	1.850	0.5	355
1.427	1.036	0.6	426
1.247	0.557	0.7	497
1.122	0.261	0.8	568
1.039	0.082	0.9	639
1.000	0	1.0	710

From this table curves may be drawn to give V_c/a_0 or V_c in miles per hour when q_L/V_L or $(p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2$ are known.

Formulæ will now be given for determining q_L/V_L for the various shapes shown in Fig. 19.

LENTICULAR AEROFOIL.

Thickness ratio

$$t/c = \tan \tfrac{1}{4}\tau$$

where τ is the angle at the trailing edge.

Maximum

$$q_L/V_L = 4 \cos^2 \tfrac{1}{4}\tau/(2 - \tau/\pi)^2 \text{ exact}$$
$$= 1 + (4/\pi)(t/c) \text{ approximately when } t/c \text{ is small.}$$

ELLIPTIC CYLINDER.

Thickness ratio t/c.

Maximum

$$q_L/V_L = 1 + t/c.$$

* Methods employed in America for the experimental investigation of aerodynamic phenomena at high speeds. By Eastman N. Jacobs. Proceedings of 5th Volta Congress, Rome, October, 1935.

OVARY SPHEROID.

Fineness ratio (maximum diameter/length) $= b/a = \cos\gamma$.

Maximum

$$q_L/V_L = \tanh Z_0 \sinh^2 Z_0/(\sinh Z_0 \cosh Z_0 - Z_0)$$
$$= \sin\gamma \tan^2\gamma/(\tan\gamma \sec\gamma - Z)$$
$$= 1 + (Z_0 - \sin\gamma)/(\tan\gamma \sec\gamma - Z_0)$$

where

$$\sinh Z_0 = \tan\gamma$$

or

$$Z_0 = \pi/10{,}800 \text{ mer. pts. } (\gamma)$$

where mer. pts. refers to the table of meridional parts in Chambers' tables.

THIN CIRCULAR ARC.

Camber $\frac{1}{2}\tan\beta$.

Lift coefficient $C_L = 2\pi\sin\beta$.

Maximum

$$q_L/V_L = 4\sin^4(\pi/4 + \tfrac{1}{2}\beta) \text{ exact}$$
$$= 1 + 2\beta$$
$$= 1 + 1/\pi \cdot C_L \Big\} \text{ approximately for small camber.}$$

EXAMPLES

Shapes as shown in Fig. 19.

LENTICULAR AEROFOIL.

$t/c = 0.157$, $q_L/V_L = 1.20$ by approximate formula.

ELLIPTIC CYLINDER.

$t/c = 0.20$, $q_L/V_0 = 1.20$.

SPHEROID.

$b/a = 0.482 = \cos\gamma$, $\gamma = 61^\circ\ 11'$, $\sin\gamma = 0.876$,
$\tan\gamma = 1.818$, mer. pts. $(\gamma) = 4{,}672$, $Z_0 = 1.358$,
$q_L/V_L = (0.876 \times 3.31)/(3.77 - 1.358) = 1.20$.

THIN CIRCULAR ARC.

Camber 0.05, $\beta = 0.1$ radians,
$C_L = 4\pi \times 0.05 = 0.628$, $q_L/V_L = 1.20$.

In all four cases

$$(p_0 - p_L)/\tfrac{1}{2}\rho_0 V_L^2 = q_L^2/V_L^2 - 1 = 0.44.$$
$V_c/a_0 = 0.74$ (using a curve drawn from the table).
$V_c = 525$ m.p.h. for $a_0 = 710$ m.p.h.

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Discussion.

Dr. Bairstow (*Fellow*): He congratulated Mr. Lock on having, in the course of three-quarters of an hour, summarized the existing position of research into compressibility effects. He had been startled to find Mr. Lock's predictions going to quite such limits though this did not imply disagreement.

This problem of how to deal with compressibility was not new; the author himself had indicated that it existed twenty years ago, but even now, after intensive study it remained very difficult to measure such things as the position of the shock wave or the temperature of the fluid in moving air. It was known that, to a very close approximation, air passed adiabatically from the container or reservoir from which the supply was drawn to the point of experiment, care being taken, of course, not to have obstructions in the way. But a thermo-junction put in the moving air would indicate a temperature nearly that of the reservoir, the reason being that the front of the thermo-junction became its own obstacle, producing a stagnation point of high pressure and therefore high temperature at the thermo-junction. If there could be devised some thermometer which was not brought to the high temperature of a stagnation point a large temperature difference would be found between the reservoir and the place where the air was moving at high speed. On the other hand a good deal of knowledge can legitimately be deduced from general theoretical considerations as to what was happening between the reservoir and the working section of a high speed wind tunnel. Sir Thomas Stanton had done one complete overall check on the validity of such deductions and others might be provided from time to time.

It was rather surprising that in a lecture like this, on wind tunnel observations, no mention had been made of Reynolds number and nothing said about turbulence. Those were matters which in normal practice occupied a great deal of time, and perhaps it was necessary to provide some kind of justification for neglecting those two quantities in high speed experiments. Such justification as there was, arises from the type of experiment shown by the Author that evening. He had shown drag curves which suddenly increased many times as the speed increased, and the reason why at this stage of the investigation it was possible to neglect Reynolds number and turbulence effects was that compressibility when it did show itself produced effects much greater than anything which had been thought of before. There was not in view any reasonable hope of building a useful aeroplane for work beyond the speed at which the compressibility still occurred.

The question arose as to how far this new development affected standard practice. He thought it had little effect so far as civil aviation was concerned. It was quite true that the tip speeds of airscrews were high and compressibility was there of some importance, but the subject was investigated at Farnborough by several workers, and for some years now it had been known with appreciable accuracy what losses were being made in running airscrews at high tip speeds. He did not think there was any suggestion from the author's curves that at speeds of 200 miles an hour there would be much trouble with any of the normal parts of an aeroplane, and it was doubtful whether commercial speeds higher than 200 miles an hour were likely for a long time to come.

In relation to stratospherical flights, where the Italians were first in this field, the problem was obviously just one of many which arose in the consideration of flight at considerable altitudes, and it seemed as though the problem of flying at 40,000 feet over long distances was one for the distant future since at the present moment there did not seem to be any reasonable prospect of solution.

A point which interested those present more closely was that some existing aeroplanes during part of their normal use travelled at high speeds. An aeroplane could reach a speed of 400-500 miles an hour by diving. For various reasons thicker sections would be liked, but the author gave them a warning that if they attempted to use thicker sections they must be prepared for con-

siderable effects due to compressibility at speeds not much greater than those now being reached.

Mr. FARREN (*Fellow*): He wished to draw attention to one aspect of the influence of high speeds (up to, say, 500 or 600 miles an hour) on the force on a body, namely, that in some cases the effect was calculable. The author had given an illustration in Fig. 7 of the paper. He had recently had a report from the N.P.L. by Mr. Lock's colleague in this work, Dr. Hilton, which showed that up to about 0.7 of the speed of sound the agreement between prediction and measurement of lift coefficient was as good as one could wish. The reason for this success was presumably that the underlying physical effect was fairly simple. The laws which governed the compressibility of air were well understood and in that particular case their application was also simple. This was an illustration of the difference between a problem which involved a fairly simple physical phenomenon such as compressibility, and one in which the physics were much more difficult, such as the effect of viscosity, with which they were often concerned.

The author ended his paper on a brave note which he much admired. He referred particularly to Fig. 19 which contained much food for thought. He doubted whether the position as there displayed was generally realised. The diagram and the part of Mr. Lock's paper which dealt with it and the following tables gave a valuable indication of where the difficulties were likely to be greatest.

The author had mentioned that it might be necessary to undertake experiments on large models capable of accommodating an airscrew of fair size, say 3 feet in diameter. That would require a tunnel considerably larger than was at present available, and he could only say that he hoped it would be possible to arrange for the provision of such equipment at a sufficiently early date, so that the information which it alone could supply would be available in time to be really useful.

He felt, however, that it was already clear from the summary of the situation which Mr. Lock had given that the economical attainment of speeds of the order of 500 or 600 miles an hour would depend on the practical realisation of a standard of streamlining, particularly in relation to details, considerably higher than the present standard, high as that was in comparison with what they had accepted a few years ago.

Dr. G. P. DOUGLAS (*Fellow*): He had not realised that it was such a simple matter to produce aeroplanes with speeds of 500 miles an hour and upwards, if the structural difficulties could be overcome.

The momentum method of tackling high speed drag was a tremendous contribution to progress and experimental technique. This method, as developed by Mr. Lock and Dr. Hilton, enabled a large aerofoil to be tested in the tunnel and gave results with a certainty such as no balance method could give, since the corrections were much more definite.

In connection with this high-speed work Prof. Bairstow had already mentioned the Italian experiments. Some very stimulating work had been done by General Crocco, concerning the possibilities of flight at these very high speeds. The work was little known in this country, but it always seemed to him of very great importance.

Dr. MACCOLL (*Associate Fellow*): The subject of compressibility in gas motions had interested him during the last few years mainly as regards its application to ballistic problems. In external ballistics the velocities usually dealt with ranged from about 800 ft. per second to over 3,000 ft. per second. The speeds with which the present paper was concerned were, therefore, at the lower end of the ballistic scale. He himself had been dealing mainly with speeds greater than that of sound, for it was found that in this region problems of fluid motion were much simpler than at lower speeds and complete solutions were often obtainable. These considerations might afford some slight consolation to designers who were

meeting compressibility problems for the first time. They might be encouraged to know that when machines could travel at speeds greater than that of sound, the aerodynamic forces could then be calculated with considerable accuracy.

There were several points with which he wished to deal very briefly. Mr. Lock had stressed the importance of the critical value of V/a at which the speed at some point in the field coincided with the local speed of sound. By a method due to Mr. Relf, he had estimated the values of this critical number for several objects. It appeared to the speaker that Mr. Relf must have covered much the same ground as had been done by Mr. Jacobs of Langley Field. Two years ago Mr. Jacobs read a paper before the Volta Congress in Rome and there he described a method for predicting the critical value of V/a from a knowledge of the greatest suction on the body at low speeds and upon the assumption that the surface pressures varied with velocity according to a definite law. These calculations appeared to be based upon fairly sound principles and the two or three examples which had been worked out had shown reasonably good agreement between the predicted and the observed values of the critical number. Professor von Kármán had indicated further that Mr. Jacobs' method could be simplified for the case of thin aerofoils and that the critical velocity was then less than the normal speed of sound by an amount which was proportional to the fineness ratio raised to the power $2/3$.

The next point concerned the accuracy of the balance measurements which the author had obtained in his high speed wind tunnel. Fig. 17 showed that the drag measurements obtained by the balance were about 30 per cent. greater than the values obtained by the pitot traverse method. It was very desirable to know whether the accuracy of balance measurements might be increased in the near future. He understood that in Germany the resistance of the same body had been measured in different tunnels and that the results obtained were not as consistent as might be desired. The suggestion had been put to him quite recently by Professor Busemann that it might be desirable if a model of specific design was tested in all the high speed tunnels of the world. There were high speed tunnels of various designs in six or seven countries and it would certainly be very instructive to have a comparison of results obtained in all the available tunnels.

Proceeding to his next point, the speaker said that, in connection with the conditions near an aerofoil as represented diagrammatically in Fig. 15, it had been realised for some time that much of the loss of lift and increase of drag at speeds greater than the critical value was due to the break-away of the flow from the surface of the body. Break-away of the main flow was closely connected with the formation of a shock wave. The conditions could be explained to some extent by the observed pressure variations at the surface itself but several points still required clarification. He thought that an interesting investigation might be carried out at a particular value of V/a to see whether it was possible to retard the formation of the shock wave or at least to displace its position to a point much nearer the tail of the aerofoil. The size of the turbulent wake would then be reduced and there would be a consequent reduction of the drag. Since shock waves were primarily due to boundary conditions it would be necessary to gradually alter the shape of the aerofoil. The contour forward of the shock wave would require no alteration, but the shape of the body behind the thickest section would need to be modified by a step-by-step process as the tail was approached. An investigation of this type would be expected to give them important information about the best shape of an aerofoil when both subsonic and supersonic speeds are present in the field surrounding the body. They had already some knowledge about the best shapes at purely subsonic or at purely supersonic speeds, but there was as yet very little known about the best shapes in the region of transition. Some work on this question could possibly be carried out with the equipment available at the National Physical Laboratory.

He had been interested to learn that the author proposed to use a thermo-couple to measure the temperature at different points in the stream. Everyone who had tried that method previously had given it up in despair because of the large dynamical heating effect. In some recent work at Guidonia in Italy an optical method of measuring the density had been devised. He did not think that an account of that work had yet appeared in Italy but one of the Italian investigators had described it before the Lilienthal Society at Munich.

The final point he had to make was concerned with the analogy between the flow of a compressible fluid and the flow of electricity in a tank of variable depth. This was the analogy which had been worked out by Professor G. I. Taylor, who had shown that very useful information could be obtained from its application. If designers ever required this particular type of information it would be a relatively simple matter for them to install such tanks in their own laboratories. As regards the conclusions which were often drawn from the breakdown of the analogy he did not think that these were quite sound. The conditions in the electrical tank were always of the type which were met in potential problems. A disturbance at any point had some effect at every other point in the tank. This condition did not hold in a compressible fluid when the speed of sound was exceeded in a portion of the field since the effect of a disturbance could then be limited to a part of the flow. If an analogy was required for the motion of a compressible fluid at speeds greater than that of sound it was necessary to choose from phenomena which had the characteristics of wave motion. This requirement was absent from the electrical tank device and it was, therefore, hardly surprising that there was a breakdown of the analogy at high speeds. Further investigations into the exact reasons for the divergence of the two solutions were, however, very desirable.

In conclusion he congratulated Mr. Lock on the excellent way he had assembled his material and hoped that in a short time he would be in a position to give a further report upon investigations in this subject.

Mr. E. F. Relf (*Fellow*) : Generally their lectures concerned the development of something which had already been investigated for some time, but Mr. Lock had had new ground to break. Various people might have different opinions as to the speeds attainable in the near future, but there was no doubt that designers would strive to go as fast as possible, both for service and commercial purposes. It was important, therefore, to explore anything that might limit speed, and compressibility was probably the most important thing that would limit speed ultimately. Mr. Lock had done his work in quite a small tunnel and had no very great facilities as yet, but it was hoped to expand these very soon, and in particular to make a second tunnel in which glass walls would be used instead of a steel cylinder. It would thus be possible to see the flow and to take photographs of a similar nature to the one which Mr. Lock had shown. Past experience of visualising flow showed that if the same thing were done in the compressible case it would add greatly to their knowledge. The exact picture of what the flow looked like was of great service in developing theories and in devising experimental researches. He also mentioned the possibility of using much larger tunnels in order to investigate points of detail, such, for instance, as the effect of the blade roots of the screw and their interference with the fuselage, a problem that Mr. Lock had mentioned. A beginning had been made in this direction by Professor Prandtl, with his new tunnel at Göttingen. If the size of an atmospheric tunnel were put up to even 6 ft. diameter, an enormous horse-power was required to get a speed of 600 miles an hour. But what could be done was to reduce the density of the air in the tunnel, and if the pressure were reduced to 1/10th of an atmosphere, a given speed could be obtained for 1/10th of the power, so that the necessary power became reasonable. This procedure involved a sacrifice of Reynolds number, it was true, but he did not believe that the Reynolds number was extremely important in these matters connected with compressibility. Exploration could be made at quite a low

Reynolds number and useful data still be obtained. Professor Prandtl had not yet got his tunnel into full running order, but some useful work might soon be expected from it. Compressibility effects could be studied with simple models in the little tunnels now in use, but the most that could be done in that way was to lay the foundations; to explore the behaviour of the forces on simple bodies and try to develop theories that would explain them. But if speeds did rise much above 400 miles an hour it would probably prove necessary to make larger tunnels where these matters could be properly studied in much greater detail.

The lecture marked an important point in the history of research development. It was a start in the investigation of a new subject, and one which was likely to turn out to be very important.

Flight Lieutenant F. WHITTLE (*Associate Fellow*): He desired to register a protest against the point of view they had heard that evening, and had heard previously, that speeds approaching the speed of sound were hopelessly impracticable. It would be most unfortunate if anybody went away with the impression that such speeds were out of the question. The conclusion which he himself drew was that they had not yet studied what were the correct stream-lines for these speeds. He wished to suggest one possible body for consideration, namely, a body whose external shape was that of a plain circular cylinder, but streamlined by having a kind of Venturi hole in the centre. A body of that shape might well have so small a variation of velocity over its external surface as compared with the general stream velocity that any shock wave effects on its external surface should be avoided. At the throat there would be, of course, a velocity as great as that of sound, and there would be a shock wave, but it would be a " self-contained shock wave," and the loss in the " tunnel " going through the body should not be any greater than the normal " nozzle loss."

Another possible experiment would be to try the effect of flattening the surfaces of the aerofoil to see if the reduction of the slope in the vicinity of these high linear velocities would modify the increase of drag. He had always understood that the actual slope of the body surface was itself an important feature in drag at speeds at or above the speed of sound. That point led him to ask if any experiments had been done to separate out the drag due to the pressure distribution from the drag due to the pure skin friction. It was most important that they should have knowledge as to how much was due to each of these.

Another point on which he personally desired to know something was as to what happened to the induced drag on a wing when the speed of sound was approached. He desired also to ask the lecturer whether he could share the magnitude of the effect of the tunnel wall on the critical speed. There was a kind of throat formed between the convex surface of the aerofoil and the tunnel wall, which would produce the sudden increase of drag at a speed much below that at which it would have happened had the wing been in the free flow.

Finally, a word on the pitot traverse method of ascertaining the drag. It appeared that the pitot traverse method might break down at these very high velocities. For one thing the pitot tube traverse alone was not sufficient and must be accompanied by a static traverse. Further, they had heard that when the shock wave occurred the change of density and pressure were not adiabatic. He therefore concluded that there was an irreversible thermo-dynamic process and therefore that there was likely to be a change of energy in the stream, manifested purely as a temperature change which, as far as he knew, the pitot tube traverse method would not reveal. The pitot tube traverse relied on the fact that the energy along the stream line could be regarded as remaining unchanged, except in the narrow boundary wake.

What was the effect on the reading of a static tube at these speeds?

Mr. R. H. CHAPLIN (*Associate Fellow*): Professor Bairstow had mentioned the possibility of stratosphere flight, but Mr. Lock had not defined the extent of the

effect of the reduced air density at altitude upon compressibility. If some explanation of this kind could be given, the clearing of this point would probably be appreciated by many present. In certain cases he had mentioned the speed without defining whether he was dealing with ground level densities or densities at altitude.

Dr. HILTON: With regard to the possibility of flying in the stratosphere at shock-stalling speeds, there was one point to be considered, namely, that due to the lower temperature the velocity of sound would be lower at high altitudes. As a given aeroplane would have a shock-stalling speed at a certain V/a, and not at a certain number of miles per hour, it followed that it would have a higher air-speed at sea-level than in the stratosphere. Due to this effect, an aircraft whose top speed was limited by the formation of shock-waves would fly some 50 or 60 miles an hour faster at sea-level than at 30,000 feet. Thus all really high-speed flying would be done at low altitude, unless the aircraft could reach the stratosphere, where winds of 200 miles an hour or more would make this diminution of speed negligible. This effect would be important, however, when attempting to raise the world air speed record from its present value (440 m.p.h.) to say 500 miles per hour, and that the ideal conditions for such an attempt would be found at sea-level in a warm climate.

Mr. M. L. BRAMSON (*Fellow*): It was always interesting to try to translate into something tangible the effects of such new developments of theory as they had heard that evening. One speaker had suggested that they should reconsider their ideas as to what aeroplanes would look like, and it seemed to arise from this paper that the almost universal predominance of monoplanes may in future be reversed in favour of biplanes with thin aerofoils. He thought it might be just as well to draw attention to that trend which might arise when it became a question of getting up into the stratosphere.

Dr. D. R. PYE (*Fellow*), Director of Scientific Research Air Ministry: Was it possible to explain in terms of simple mechanics just where the rapid increase of the drag co-efficient arose when a shock wave set in?

With regard to Fig. 15, was it supposed that the boundary layer for the front of the aerofoil remained more or less normal and that the increase of drag co-efficient was due to an exceptionally low pressure in the turbulent wake? If that were so, could the lecturer explain how the fall of total head at a considerable distance from the aerofoil axis, which was indicated in the figure, was related to the increased drag forces on the aerofoil?

REPLY TO THE DISCUSSION.

He would commence his reply by dealing with the two items of the discussion which seemed to require the most detailed examination. Dr. Pye had asked a question about the mechanism by which a shock wave gives rise to an increase of drag. Dr. Maccoll had mentioned that part of the drag was associated with a break-away of the boundary layer at the shock wave, and about this part there was presumably no difficulty. With regard to the part more directly caused by the shock wave, the lecturer supposed that just as there existed in a compressible non-viscous fluid at speeds below the " shock stall " a continuous flow round any body with slip at the boundary which gave zero drag, so at higher speeds there existed a unique flow continuous everywhere except at a limited shock wave; the shock wave itself would have a unique configuration and intensity at every point of its surface. There was as already explained an appreciable flow of heat across the shock wave, and hence an increase of entropy of the air stream as it crossed the shock wave. It followed that a continuous supply of external energy was necessary to maintain the system in relative steady motion, this energy would reappear in the wake and must be supplied by a form drag on the body moving through the fluid. In the ideal case it was to be assumed that there was no conduction of heat except at the shock wave and no

turbulence, and so there was no tendency for the wake of the shock wave to spread out indefinitely at a large distance behind the body. The ultimate wake would be at standard pressure; its velocity would be everywhere parallel to the incident stream but would be reduced in magnitude while the density would be reduced and the temperature increased. The flow of momentum in the wake would, therefore, be less than in the initial stream and the difference would be equal to the form drag on the body. Unfortunately no one had yet succeeded in obtaining a solution of the above type of the non-viscous equation of a compressible fluid flowing round a body with limited shock waves; if such a solution were ever obtained it would be possible to trace in detail the transmission of pressure and energy from one part of the fluid to another.

It would be of great interest if the proportion of the drag due to the shock wave corresponding to the ideal case and the proportion due to break-away of the boundary layer could be evaluated. The evidence from wake explorations was that for thin sections the direct effect of the shock wave was more important than the break-away, but that the reverse might hold for thick sections. Dr. Maccoll made the interesting suggestion that the effect of the break-away might be reduced if the shock wave could be pushed further back by altering the shape of the rear portion of the aerofoil. Against this there was the evidence of the American pressure plotting and photographs, which showed that the shock wave moved towards the tail of the aerofoil as the speed increased, while at the same time the drag increased very rapidly. This suggested that the unavoidable drag due directly to the shock wave was the more important at the highest speeds.

The rest of the discussion might be dealt with more briefly and would be taken in order.

In reply to the Chairman and Professor Bairstow, he regretted that he had not had the space to go into more detail on the subject of the experimental technique. The chief difficulty of the experiments was the lack of time available especially at high speeds. At top speed the whole of the compressed air tunnel full of air would only last for about 20 minutes. It was therefore necessary to compromise on the size of a total head tube for exploring the wake; too small a tube would be too sluggish. The actual sizes used ranged from about 0.014″ to 0.023″ internal diameter, the larger size being used for the highest speed for which the wake was wider and the saving of time more important. Some of the later observations were made with a " comb " of pitot tubes, by which it was hoped to get a number of readings simultaneously by photographing a multi-tube manometer, but it was not possible to place the tubes close enough together to avoid traversing the tube into a few different positions.

He quite agreed with Professor Bairstow and Dr. Maccoll that measurements of temperature in the wake were very difficult. They had quite recently achieved some small measure of success in getting some curves in the wake, but they still did not quite know what they meant. They considered it best to try to measure the " stagnation temperature " because the effect of losses either in the shock wave or in the boundary layer would be an increase of entropy, and when there was an increase of entropy, the stagnation temperature would differ from the temperature upstream. For this purpose they used a thermocouple placed just inside the mouth of a pitot tube made of insulating material.

Professor Bairstow had mentioned the question of Reynolds number and turbulence in these tunnels. He quite agreed with him that there was every reason to believe that the very large increase of drag due to shock-stalling might be largely independent of the Reynolds number. The actual turbulence in the high-speed tunnel he believed to be very low, because the air was started up rapidly from rest and had a very short distance to go.

It had also been suggested by Professor Bairstow that the aeroplane could not hope to fly at high speeds because of the shock-stall. That, of course, was perfectly true if one had the shock-stall over the complete aeroplane, but it seemed to him that the whole point of their study was to find out the causes of shock-

stalling over small portions of the aeroplane, and if a shock-stall over a small portion was unavoidable this might not prevent the aeroplane getting up to that speed. They would then like very much to know how much and how bad the effect was for that particular detail.

With regard to Mr. Farren's remark about the obviousness of the results on ellipses and spheroids, he had to confess that he had feared at first that the results might seem trivial. He was gratified to hear that some people had found them interesting. The actual low-speed calculations on which they were partly based were, of course, very well known to students of hydrodynamics. He had decided to include details of the actual formulæ employed in an Appendix to the printed paper for reference. He had recently seen a paper in the Phil. Mag. by Dr. Piercy and others describing a new theoretical aerofoil shape in which the position of the maximum thickness could be varied. This might be useful for high speed work. He hoped with Mr. Farren that facilities for testing airscrews at high speeds would materialise but in the meantime he proposed to make a start on the problem of airscrew blade roots by testing suitably shaped tapered aerofoils.

Dr. Douglas had mentioned the paper by Crocco which he had read not long ago with great interest. It contained some most interesting speculations on the possibility of flight above the velocity of sound in the stratosphere. He himself had not felt equal to such an extensive flight of imagination.

Dr. Maccoll's remarks were of extreme interest and would be a great help to him and his fellow-investigators in their future work. He agreed with him that the mathematics of flying above the speed of sound was easier in some respects than that concerned with the intermediate region with which he had had to deal. He had quoted the formulæ given by Jacobs in the Appendix to the printed paper, and regretted that due acknowledgment was overlooked at the time of the lecture.

He welcomed the suggestion of international trials with high-speed tunnels. In the paper would be found a comparison with the American tunnel in one case in which the agreement was reasonably good. As a possible source of difficulty he might mention the fact that they got a deposit of soot on their aerofoil under ordinary conditions which might by itself be enough to upset the drag. Dr. Maccoll's remarks about the shock wave had already been dealt with.

He had been interested also in the suggestion of an optical method of measuring density. The question of measuring temperature did not appear to have a very great importance from the practical point of view of determining drag by the pitot traverse method, because the possible uncertainty of density in the wake would correspond to an uncertainty of only a few degrees—say 10 degrees C. at the most—which would lead to only a small percentage uncertainty in the density and a corresponding small percentage uncertainty in the drag.

They had all been very much interested in Mr. Relf's description of the German high speed wind tunnel. A larger size of wind tunnel would greatly facilitate experiments on a model with airscrews running even if the Reynolds number were not increased.

Flight Lieutenant Whittle had mentioned the possibility of investigating other shapes, including rather curious shapes, for example, a cylinder with a hole through it. It seemed to him that a thin cylinder would presumably have no drag at all, but he did not quite see where the pilot was to be placed or how such a construction was to be of service.

With regard to variation of slope of the surface of an aerofoil, although it was true that above the velocity of sound the slope of the surface was closely bound up with resistance, he believed that at the lower speeds with which he had to deal the maximum velocity at low speeds was the determining factor and that the ellipse was probably near the theoretical optimum shape.

The question of separating the drag due to pressure distribution from the drag due to pure skin friction was of great interest. He had given some account of the form drags deduced from the American high-speed tunnel pressure plotting results, and they seemed to show roughly the same rate of increase as the coefficient of total drag in their own tunnel

He was afraid that he had not yet given much consideration to the question of what happened to the induced drag. Up to fairly considerable speeds it might be hoped that the relation between the induced drag and lift would be the same as at low speeds. Some attempt had been made to allow for tunnel wall correction by testing two different sizes of aerofoil of similar shape.

As regards the possible breakdown of the pitot traverse method it must be remembered that this was based on the evaluation of rate of flow of momentum, and was therefore unaffected by energy losses provided that the momentum could be correctly evaluated. After careful consideration they had come to the conclusion that this could be done even if local shock waves were present (apart from the uncertainty of density which was not serious) provided only that the speed in the section traversed was everywhere below the velocity of sound. Direct experiment had shown that a typical static tube gave correct readings up to speeds quite close to the speed of sound.

In answer to Mr. Chaplin's question the speed of sound assumed in most of the calculations in the paper was 710 miles per hour, corresponding approximately to an altitude of 20,000 ft. The speed of sound depended of course on the temperature and was otherwise independent of pressure and density.

He did not altogether agree with Dr. Hilton that the speed record would necessarily always be confined to sea level since the decrease of drag due to the reduction of density at 30,000 ft. might be enough to outweigh the reduction of the speed of sound.

Mr. Bramson had mentioned the possibility of reducing the maximum thickness of wings by reverting to the biplane. The difficulty would be in doing this to avoid a great increase of drag from the necessary bracing structure. He had recently read a paper by a German author who had devised a pair of wing sections which would theoretically have a very low drag above the speed of sound.

The CHAIRMAN: He asked the members to show their appreciation of the lecture in the usual way, and said that the discussion had been a particularly good one, as might have been expected from a paper which dealt with a novel subject and had been so well handled. The possibilities and difficulties had been very clearly brought out, and he hoped that some of the designers, who were not particularly well represented at the meeting that evening, would find, in the not too distant future, some applications of this work in the practical solutions of their problems.

The vote of thanks was accorded and the proceedings terminated.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

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(Prepared by R.T.P.)

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On the Stability of Kármán's Vortex Street. (Bl. Dolaptschiew, Z.A.M.M., Vol. 17, No. 6, Dec., 1937, pp. 313-23.) (52/1 Bulgaria.)

The author deals with the behaviour of Kármán's vortex street in the case of disturbances of the second order. Two special kinds of disturbances are introduced: "Uniform" and "alternating." It is shown that in the first approximation both kinds of disturbances lead only to a translation. In the second approximation, an instability seems to appear in the case of alternating disturbances. A closer examination by the author shows, however, that this instability cannot actually arise.

Further Studies of the Ground Effect on the Aerodynamic Characteristics of an Aeroplane, with Special Reference to Tail Moment. (I. Tani, H. Itokawa and M. Taima, Aer. Res. Inst., Tokio, Report No. 158, Nov., 1937, pp. 117-45.) (52/2 Japan.)

The present paper deals with the effect of the ground on the aerodynamic characteristics of an aeroplane, with special reference to the effect on the tail-plane characteristics. Results of wind tunnel tests on a low-wing monoplane model show that the effect is of considerable importance. The changes in the lift and drag characteristics are quite similar to those for a wing alone, which have been fully discussed in Report No. 156. The pitching moment becomes definitely nose-heavy owing to the effect of the ground, so much so that this may in some cases necessitate alterations in the design of the elevator.

Satisfactory estimates of the foregoing effects may be obtained by theoretical calculation, although it seems that theory somewhat underestimates the effect on lift when the trailing edge flaps are working. The correlated error in the pitching moment is negligibly small.

Efflux of Gases through Orifices—Kinetic Theory. (B. V. Korvin-Kroukovsky, J. Frank. Inst., Vol. 225, No. 1, January, 1938, pp. 81-93.) (52/3 U.S.A.)

The efflux of gases through orifices was treated heretofore on a basis of adiabatic expansion, postulating a decrease of temperature, which is not observed in everyday experience. Consideration of molecular motion (kinetic theory) shows the possibility of the expansion of a gas through an orifice without change of temperature, and permits the formation of simple quantitative relations which are in a satisfactory agreement with test data. For small difference in pressure

the new expression for discharge becomes identical with Fliegner's formula. It is explained that reduction of temperature postulated by adiabatic formulæ should be understood to apply to the observer moving with stream, and that no change of temperature is registered by a stationary observer. From a consideration of the reduced number of impacts between molecules with reduction of the pressure ratio, the new " kinetic " formulæ are extended to include critical flow phenomena.

Universal Logarithmic Law of Velocity Distribution as Applied to the Investigation of Boundary Layer and Drag of Streamline Bodies at Large Reynolds Number. (G. Gurjienko, Report No. 257, Central Aero-Hydrodynamic Institute, Moscow, 1936. Available as Translation T.M. 842.) (52/4 U.S.S.R.)

The logarithmic law of velocity distribution of Kármán, applied to a figure of revolution and to a flat plate with the generally accepted value of $K = 0.4$, gives too sharp an increase in the boundary layer thickness and too small values for the drag.

This is due to the fact that a much smaller value of the constant K ($K_1 = 0.2 - 0.3$) corresponds to that region where the logarithmic velocity distribution law is actually applicable (i.e., where the effect of viscosity is negligible).

If the logarithmic law is applied to the region near the wall where the effect of the viscosity shows up strongly and where the law, strictly speaking, is not applicable, an error in principle is made which it is possible to compensate by taking $K = 0.4$.

Since a variable K cannot be introduced, it is proposed that in the formula for the velocity distribution a value $K_1 = 0.2 - 0.3$ be taken, and in the formula for the drag, $K = 0.4$.

This, of course, only represents a temporary expedient and the search for a more general law covering all states of flow is one of the most urgent problems in hydrodynamics.

The Two-Dimensional Hydrodynamical Theory of Moving Aerofoils—II. (R. M. Morris, Proc. Roy. Soc., Series A, Vol. 164, No. 918, 4/2/38, pp. 346-68.) (52/5 Great Britain.)

The previous solution of the problem of a general cylinder moving in liquids is generalized to include the effect of a vortex-sheet wake extending backwards in the liquid from a trailing edge. Assuming the wake to be of any shape and to have associated with it a total circulation which is equal and opposite to that of the main circulation round the cylinder, general formulæ are derived for the potential function of the fluid motion and the resultant of the fluid pressures on the cylinder boundary.

It is shown that under the usual conditions assumed for the wake, the lift force produced is greater than that produced by the corresponding simple circulation, and that this greater lift is attained without the drag which accompanies it in the simple circulation.

Pressure Distribution Over a Clark Y-H Airfoil Section with a Split Flap. (C. J. Wenzinger, N.A.C.A. Tech. Note No. 627, December, 1937.) (52/6 U.S.A.)

An investigation was made in the N.A.C.A. 7 by 10 foot wind tunnel of the distributions of air pressure over one chord section of a Clark Y-H aerofoil with a split flap. The results obtained are given in the form of diagrams showing the chordwise distribution of pressure on both aerofoil and flap and as plots of calculated aerodynamic coefficients for both aerofoil and flap. (six references.)

Free-Spinning Wind Tunnel Tests of a Low Wing Monoplane with Systematic Changes in Wings and Tails. II—Mass Distributed Along the Fuselage. (O. Seidman and A. I. Neihouse, N.A.C.A. Tech. Note No. 630, December, 1937.) (52/7 U.S.A.)

Eight wings and three tails, covering a wide range of aerodynamic characteristics, were independently ballasted so as to be interchangeable with no change in mass distribution. For each of the 24 resulting wing-tail combinations, observations were made of the steady spin for four control settings and of recoveries for five control manipulations, the results being presented in the form of charts comparing the spin characteristics. The tests are part of a general investigation that is being made in the N.A.C.A. free-spinning tunnel to determine the effects of systematic changes in wing and tail arrangement upon the steady spinning and the recovery characteristics of a conventional low-wing monoplane for various loading conditions.

For the tails having a deepened fuselage and a raised stabiliser, recovery was satisfactory and the results were very similar to those previously reported for the basic loading condition. For the more nearly conventional tail, the effects of wing plan form and tip shape were quite marked and there appeared to be an adverse effect of the present loading, except for the case of N.A.C.A. 6718 section, which gave more rapid recovery than for the basic loading condition.

Pressure Distribution Over an N.A.C.A. 23,012 Aerofoil with an N.A.C.A. 23,012 External Aerofoil Flap. (C. J. Wenzinger, N.A.C.A. Report No. 614, 1938.) (52/8 U.S.A.)

Pressure distribution tests of an N.A.C.A. 23,012 aerofoil with an N.A.C.A. 23,012 external aerofoil flap were made in the 7 by 10 foot wind tunnel. The pressures were measured on the upper and lower surfaces at one chord section on both the main aerofoil and on the flap for several different flap deflections and at several angles of attack.

The data are presented in the form of pressure-distribution diagrams and as graphs of calculable coefficients for the aerofoil and flap combination and for the flap alone. The pressure distribution tests showed that, as with other types of flap, the greater part of the increment of total maximum lift due to deflecting the external aerofoil flaps downward arises from the increased load carried by the main aerofoil.

When the plain and flapped aerofoils are compared at the same angle of attack, it is apparent that the flap influences the air flow around the main aerofoil so that the aerofoil carries a much greater load without stalling than is possible without the flap.

Investigation of the Effect of the Propeller Slipstream on the Downwash and the Elevator Efficiency. (H. B. Helmbold, L.F.F., Vol. 15, No. 1/2, 20/1/38, pp. 3-8.) (52/9 Germany.)

The propeller slipstream usually reduces the longitudinal stability of an aeroplane to an appreciable extent.

The stability mainly depends on the downwash and on the elevator efficiency, and the author investigates the effect of the propeller slipstream on each of these factors separately.

The results are compared with model experiments, including British tests.

In most cases the agreement is satisfactory and substantiates the modern theory of downwash.

Wind Channel Tests on Aerodynamic Brakes. (D. Fuchs, L.F.F., Vol. 15, No. 1/2, 20/1/38, pp. 19-27.) (52/10 Germany.)

When diving aerodynamically efficient aircraft, the terminal velocity may become unduly high. A simple remedy is here provided by fitting aerodynamic

brakes. Such brakes may, however, alter the longitudinal moment and the zero lift line. In addition the wake behind the brake may reduce the efficiency of control surfaces and induce flutter.

These drawbacks are overcome by a proper choice of position and dimensions of brake. As a result of his model experiments, the author recommends fitting the brake on the lower surface of the wing in close proximity to the front spar. Under these conditions, a tail-heavy additional couple is introduced which reduces the diving moment. The provision of a slot between the brake and the wing reduces the troublesome effects of the wake without affecting the braking action.

The Development of the Catapult by the Heinkel Aircraft Works. (K. Schwarzler, L.F.F., Vol. 15, No. 1/2, 20/1/38, pp. 48/53.) (52/11 Germany.)

The following table gives the principal characteristics of the compressed air catapults developed by Messrs. Heinkel.

Type	K_1	K_2 and K_4	K_8	K_{10}	K_{11}
Launching speed (Km./h.)	105	108	105	150	150
Weight of aircraft (Kg.) ...	2,500	3,500	3,000	18,000	18,000
Weight of carriage (Kg.)	400	406	290	2,100	1,700
Weight of installation (Kg.)	—	23,440	13,220	95,000	—
Air pressure (atm.)	85	80	85	180	140
Launching run (m.) ...	11.85	20.00	13.40	31.60	31.5
Retardation run (m.) ...	2.20	3.00	2.70	5.75	6.68
Acceleration mean (g.) ...	3.65	2.30	3.24	2.80	2.80
Acceleration max. (g.) ...	4.92	3.00	4.00	3.50	3.50
Retardation mean (g.) ...	19.7	15.30	16.10	15.40	13.20
Retardation max. (g.) ...	30.0	25.0	22.0	32.0	21.50
Launching time (sec.) ...	0.81	1.33	0.92	1.52	1.51
Launching work (m.t.) ...	108.5	160	130	1,600	1,600
Average H.P.	1,760	1,600	1,880	14,000	14,100

K_1 was the first type experimented with in 1925. K_2 and K_4 are fitted to the ocean liners " Bremen " and Europa " for catapulting the postal planes. K_8 is a military version of K_4 built for the Dutch navy. K_{10} and K_{11} represent the latest types with a launching work capacity of 10 times that of K_2 or K_4. K_{10} has been used with the seaplane H_a136 in its north Atlantic crossings. The article gives some constructional details of the catapults, the most interesting feature being the air admission valve.

Improvement of Aileron Effectiveness by the Prevention of Air Leakage Through the Hinge Gap as Determined in Flight. (H. A. Soule and W. Gracey, N.A.C.A. Tech. Note No. 632, January, 1938.) (52/12 U.S.A.)

A flight investigation was made of the increase in effectiveness of ailerons that can be obtained by preventing flow of air through the wing at the hinges and of the possibility of reducing the aileron operating force by replacing ailerons having normal open hinge gaps with narrower but equally effective ailerons having sealed hinge gaps. Tests were made with a Fairchild 22 aeroplane with two sizes of plain unbalanced ailerons, one set having a chord equal to 0.18C. and the other a chord equal to 0.09C.

The results of the investigation show that improvement in the lateral-control effectiveness is obtained by completely preventing the flow of air through the wing at the hinge axis of conventional ailerons. The magnitude of the improvement depends on the aileron chord. For the 0.18C. ailerons the gain in aileron effectiveness due to sealing the gap at the hinge axis was of the order of one-fifth and for the 0.09C. ailerons the gain was about one-third. The importance of

sealing the gap was demonstrated by the fact that the 0.09C. ailerons with a slight increase in deflection range were made as effective as the 0.18C. ailerons with an unsealed gap but required only about one-third as large an operating force.

Smoke Wind Indicators on Landing Grounds. (Rev. de l'Arm. de l'Air, No. 101, December, 1937, pp. 1397-1402.) (52/13 France.)

The article describes the smoke wind indicator recently installed at the Bourget aerodrome.

The smoke is produced by an automatic oil burner supplying hot air into which the smoke producing substance is injected. The smoke produced is very white and can be controlled from the control tower of the aerodrome (start, stop, continuous or intermittent emission). In the latter case, the smoke can be used for signalling purposes (Morse code).

The system can be advantageously adapted to the marking out of emergency landing grounds in wartime, since it can be put out of action immediately.

Fixed Wing Gyroplanes. (J. H. Crowe, Airc. Eng., Vol. 10, No. 108, Feb., 1938, pp. 39-46.) (52/14 Great Britain.)

The advantages and disadvantages of the fixed wing for gyroplanes are examined. On the simplest assumptions an expression for the percentage load taken by the fixed wing of a gyroplane is derived. The values so arrived at are compared with those found by experiment and the discrepancy between the two is explained in terms of the increased downwash at the centre of the disc of the gyroplane. It is shown that as much as 50 per cent. of the weight of the aircraft can be taken by the wing at top speed with moderate wing area and the most suitable setting. The advantages of an adjustable wing from the point of view of rotor speed control are pointed out. The lift/drag of the combination is raised by 2 over lift/drag of the rotor alone. The stability of gyroplanes is discussed.

Twenty-Third Annual Report of the National Advisory Committee for Aeronautics, 1937. (52/15 U.S.A.)

Of special interest is the reference to new equipment under construction, which includes:—

(1) 19 × 3 feet atmosphere wind tunnel for air speeds beyond 200 m.p.h. This will enable the carrying out of model experiments at a higher Reynolds number than previously possible.

(2) $7\frac{1}{2} \times 3$ feet refrigerating wind tunnel for studying problems connected with ice formation on aircraft.

(3) Free flight wind tunnel 20 feet in diameter for the study of stability, control and motion of a model undergoing unrestrained flight.

The total amount of money available for general expenditure during the fiscal year 1937 was over $2\frac{1}{8}$ million dollars.

The following are two quotations from the Report.

> "No money estimate can be placed upon the economic value of greater national security through the development of the means of producing superior military aircraft . . . . . .
>
> "The research of this Committee, however, can be measured in dollars and cents . . . . . the annual savings made possible by the Committee's researches exceed the total appropriations for this organisation since its establishment in 1915."

Fire Protection in Harbour Works. (W.R.H., Vol. 18, No. 18, 15/9/37, p. 280.) (52/16 France.)

The principal recommendations are the following:

1. The goods stored must be separated into inflammable and relatively safe varieties which are housed separately.
2. Similar differentiation must be made between goods which are intended for long storage and those which are only in transit.
3. The sheds housing the goods must be provided with subdivisions (fire resisting walls) and safety doors.
4. Automatic sprinkler systems should be installed working in co-operation with foam gear.
5. It is most important that fire fighting squads should be organised amongst the regular employees, so that no time is lost in taking emergency measures (foam gear, shutting fireproof doors, &c.).

It is pointed out that the Port of London, apart from fire floats, relies entirely on the help of the London Fire Brigade in case of emergency. There is no trained personnel on the spot and no fire fighting appliances are available. Moreover only a few of the latest storing sheds (in Victoria Docks) are fitted with sprinklers.

The Most Recent Development in Machine Guns Outside Germany. (H. Nareth, W.T.M., Vol. 41, No. 4, April, 1937, pp. 178/185.) (52/17 Germany.)

The article is mainly concerned with heavy machine guns intended to combat tanks and aircraft. The usual calibre varies between 12 and 14 mm., the Hudson machine gun (U.S.A.) going up to 28 mm. In the latter case the rate of fire is 150 rounds a minute. For the smaller calibres, rates of fire up to 800/minute are possible, the bullet weighing approximately 50 gm.

In most designs the barrel is stationary, the breech mechanism only undergoing oscillations under the combined action of the explosion gas pressure and a control spring. Special reference is made to the Browning gun (U.S.A.), in which the barrel also executes a short recoil against oil pressure. The oil damper is adjustable for altering rate of fire from 600/minute to single (individual) shots.

Aeronautical Consequences of the Berlin-Rome "Axis." (A. Langeron, Les Ailes, No. 864, 6/1/38, p. 10.) (52/18 France.)

The author points out that in the war period 1914-18, Germany was able by itself alone to withstand successfully an Anglo-French industrial coalition.

All the available information seems to indicate that conditions have not appreciably changed and that France would be in a tragical position if opposed alone to Italy and Germany.

The author suggests that efficient aircraft factories be organised in those Central European countries which are friendly to France, and that in addition to British help closer co-operation with Russia should be attempted.

The best solution of all would, however, be a foreign policy directed towards a better international understanding and a curbing of the present armament race.

Smoke Producing Apparatus. (British Patent No. 472,067.) (G.E.C., J. Soc. Chem. Ind. (Abstracts B), Vol. 57, January, 1938, Abstracts p. 25.) (52/19 Great Britain.)

Evaporation of drops of oil without combustion is effected on a surface which is heated by means other than combustion; preferably an electric resistance is used. The surface is roughened, e.g., by using a gauze. The smoke is blown away by a fan producing such a strong current of air that combustion is inhibited.

Army Co-operation—Light Aircraft v. Autogyro. (R. Michel, Rev. de l'Arm. de l'Air, No. 101, Dec., 1937, pp. 1367-9.) (52/20 France.)

High speed aircraft are unsuitable for army co-operation purposes. Not only does the speed render observation difficult, but such machines cannot land in an emergency without the gravest risk. What the army requires is low speed aircraft which can land almost anywhere and for this purpose the Author recommends low powered aircraft (light aeroplanes) constructed out of wood. Such aircraft is cheap to build, the materials are available in France and quantity production could proceed without affecting the output of fighters and bombers which must be built of metal. Modern light aircraft can be built to have practically the same performance as the autogyro aircraft which is considered unsuitable for war purposes on account of its vulnerability and complicated maintenance.

Co-operation Between Tanks and Aircraft (Austrian and German Military Opinions). (Rev. de l'Arm. de l'Air, No. 101, Dec., 1937, pp. 1393-6.) (52/21 ——.)

An interesting discussion on this subject has been going on in the German Military Press for some weeks. According to the Austrian General Eimannsberger, co-operation between tanks and aircraft should make a quick decision on land possible, *i.e.*, a modern mechanised army should be able to overrun the enemy.

In view, however, of developments in modern quick fire artillery, the German authorities taking part in the discussion are of the opinion that a break through even when supported by a specially trained air force will not be possible. Any future war will last for an appreciable time till the morale of the civilian population has been broken. For this reason it will be better to have an independent air force operating against the supply system of the enemy (food depots, munition works etc.).

Targets of this type are more commensurable with the risk run than if low flying aircraft attempt to inflict losses on a ground army.

Anti-Aircraft Shells Detonated by Light Rays. (French Patent No. 803,882.) L. M. Ericsson, Rev. de l'Arm. de l'Air, No. 101, December, 1937, pp. 1417-9.) (52/22 France.)

Two rings of lateral orifices are provided on the shell, one ring being situated near the nose, whilst the second is close to the base of the shell.

Light is emitted through one set of orifices by the combustion of a special powder. If the shell passes near the target, the light reflected from the target enters the other set of orifices and operates a photoelectric relay which initiates the detonation of the shell.

Compensating devices to rule out the effect of stray illumination are described.

Improvements in the Design of Aircraft Bombs. (French Patent No. 809,077.) (M. Sabathe, Rev. de l'Arm. de l'Air, No. 101, December, 1937, p. 1420.) (52/23 France.)

The principal objects of the invention are the following:—

1. The explosive charge and the fuse are introduced into the bomb through separate orifices.
2. Charge and fuse are separated by a bulkhead so that no mixing can take place during the handling of the bomb.
3. The bomb will only explode if it strikes the ground with a considerable force and is thus safe if accidentally dropped near the ground and will even withstand a forced landing of the aircraft carrying the bomb.

In the design illustrated, the explosive is housed in a porcelain container inserted in the bomb body and provided with a filling orifice at the tail. The fuse can only operate if the casing at the nose is torn off by a drop from a great height.

Friction in Aircraft Supercharger Impellers. (V. Varley, Aeron. Eng., U.S.S.R., No. 6, June, 1937, pp. 61-75. Original in Russian.) (52/24 U.S.S.R.)

1. The coefficient of friction for an open-type impeller does not depend
   (*a*) On the circumferential speed of the rotating impeller; this has been confirmed by experiments in which the velocity was varied from 60-160 m./sec.
   (*b*) On the quantity of air passing through the impeller.
   (*c*) On the clearance between the fixed casing and the rotating impeller; in the experiments quoted this was varied between 0.5 and 1.9 mm.

2. The coefficient of friction depends only on the construction of the impeller (*i.e.* the shape and number of its blades and the diameter.) The coefficient of friction may be calculated from the following empirical formula, deduced from experimental results

$$\beta = C + (2.33/100)\,(300 - D)$$

where D is the diameter of the impeller, and
C is a number depending on the type and number of the blades.

A table of numerical values for C is given.

3. In the case of all open impellers, the friction varies according to a parabolic law. The speed exponent for all impellers tested varied around 2.9, *i.e.*

$$N_r = An^{2.9}$$

where the constant A depends on the number of blades and the diameter of the impeller.

The Cooling of the Turbine Blades of Exhaust Driven Superchargers. (J. Oderfeld and J. Sachs, Les Ailes, No. 864, 6/1/38, p. 7.) (52/25 ——.)

The following schemes for cooling the turbine blades are already in use or have been proposed.

1. Rotor cooled by slipstream, the turbine (open delivery) being placed outside the fuselage. This method is extensively used in the U.S.A. (G.E.C. construction).

2. Alternate air and exhaust discharge nozzles are used. Disadvantages are high shock losses and wear.

3. Lorenzen proposes hollow turbine blades, the cooling air being compressed in the rotor and utilised for supercharging. In a more recent design, the combination of turbine and compressor in one unit is given up, the cooling air being discharged to atmosphere.

4. Messrs. Brown Boveri attempt to cool the blade (hollow) by discharging the air through a number of holes placed near the nose of the blade. It is claimed that a heat insulating boundary layer is formed which prevents direct contact with the exhaust.

After pointing out the disadvantages of the above methods, the authors describe their own solution (Polish Patent No. 23,525) which consists in placing a circular hoop round the blade tips and providing this hoop with a number of circumferential fins which run in a chamber in communication with the slipstream.

Piston Rings—The Theory Underlying the High Point Design. (N. Stern, Autom. Eng., Vol. 28, No. 367, January, 1938, pp. 27/28.) (52/26 January.)

The author is of the opinion that ring vibration (flutter) in the groove plays an important part in the subsequent wear both of the ring and cylinder. This vibration is set up by the action of the gases during the combustion stroke. As a remedy for damping out the ring "flutter" the author suggests a deliberate increase of the radial pressure (mainly over the gap portion) of the ring when fitted. An increase in static ring pressure over that usually employed is not

considered objectionable, since the effective radial pressure during the combustion stroke leads in any case to a large increase.

Wind Tunnel Tests of Carburettor Intake Rams. (F. H. Highley, N.A.C.A. Tech. Note No. 631, January, 1938.) (52/27 U.S.A.)

An investigation was conducted in the N.A.C.A. 20 foot wind tunnel of the ramming effect of three general types of carburettor-intake rams for radial engines, namely, the internal constant-area type, the external constant-area type, and the external expanding type. The rams were installed on a radial air-cooled engine nacelle and tests were made with and without the propeller operating.

The internal constant-area type secures air for the carburettor from within the engine cowling and forward of the engine cylinders. The external constant-area type secures air for the carburettor from the air stream outside the engine cowling. The external expanding type secures air at high velocity from the air stream outside the engine cowling and reduces its velocity and increases its pressure by an expanding tube before it reaches the carburettor.

The results indicated that: The external types having entrances near the front of the engine cowling gave the greatest ramming effect and these results are still further increased by the effect of the propeller.

Spark Plug Endurance Tests with Special Reference to the New Scintilla Aircraft Plugs. (Autom. Ind., Vol. 78, No. 3, 15/1/38, pp. 87-8.) (52/28 U.S.A.)

The plug (designated as Bendix 5AFL) has a central one piece electrode surrounded by a copper tube, which rests on the inner surface of the electrode nose and is intended to assist in the heat dissipation. The electrode is mica insulated and the external plug body is provided with 15 deep cooling fins.

The ground electrode is of the adjustable 4 prong baffle type, the nose of the central electrode being spherical and of considerable area. By the choice of suitable material, erosion is limited to the baffle which can be easily replaced. It is claimed that the baffle action prevents the accumulation of lead and other foreign matter and that the plug has operated satisfactorily for 500 hours on a high duty engine without requiring any adjustment.

Supercharging Effect on Diesel Engines. (Autom. Ind., Vol. 78, No. 3, 15/1/38, pp. 88-9.) (52/29 U.S.A.)

To obtain full advantage from supercharging, the combustion chamber must be fully scavenged by providing sufficient blower pressure and valve overlap. Engines using a precombustion chamber may require an auxiliary valve to ensure this.

A piston or roots blower is preferable to a centrifugal supercharger as the characteristics of the former are less affected by engine speed.

The location of the blower drive is extremely important (torsional vibrations) and satisfactory results can only be obtained if the engine is designed for supercharging from the outset. Tests show that for a 50 per cent. increase in power, both piston temperature and specific fuel consumption are not affected to an appreciable extent. For rail cars, switching locomotive and heavy motor trucks, the author considers the supercharged Diesel engine as definitely superior (from the point of view of cost and weight) to a normal design of equivalent power.

More About Supercharging Diesel Engines. (Autom. Ind., Vol. 78, No. 3, 15/1/38, pp. 89-90.) (52/30 U.S.A.)

Supercharging a Diesel engine has a beneficial effect on the engine, since the ignition lag is reduced and the exhaust valve cooled by the scavenge. The reduction in ignition lag stops high gas pressures associated with late combustion and this in its turn reduces bearing loads and torsional vibrations.

In the past, supercharging has not been extensively applied, partly on account of prejudice and partly on account of cost. It is thought however that this will change as the inherent advantages of supercharging, especially when applied to the Diesel engine, are more generally realised and an increased experience renders higher degrees of supercharge possible.

In the present state of development, it is not yet possible to say which of the various types of superchargers (piston, roots, centrifugal or turbo blower) will ultimately hold the field.

Experiments with a Two-Stroke Diesel Engine. (H. List and E. Niedermayer, Forschung, Vol. 8, No. 6, November/December, 1937, pp. 265-78.) (52/31 Germany.)

The experiments were carried out on a 2-stroke engine of 120 mm. bore and 180 mm. stroke operating at 700 r.p.m. and the research is a continuation of previous work (both theoretical and practical) carried out by the authors on larger engines.

The scavenging efficiency of a 2-stroke is defined as:—

$$\eta_s = 1 - v'/v$$

where $v' = CO_2$ content of compressed charge before ignition, and
$v = CO_2$ content of exhaust.

Instead of measuring the CO_2 content of the charge by means of a sampling valve, the whole of the charge is transferred to the sampling capacity by means of a subsidiary delivery valve, working in conjunction with the engine piston. For this purpose the piston is split, the upper portion (crown) remaining in T.D.C. position as soon as the gas pressure is relieved. Experiments were also carried out with various degrees of supercharge, for which purpose a rotary valve was incorporated in the exhaust pipe. Scavenging efficiencies of the order of 95 per cent. were obtained with an excess air coefficient of 1.50. Of special interest is the calculation of the heat transfer coefficient during the scavenging process.

The Ignition and Combustion Process of Diesel Engines Working on the Vortex Chamber and Air Capacity Principle. (H. Petersen, Forschung, Vol. 8, No. 6, Nov./Dec., 1937, pp. 279-84.) (52/32 Germany.)

The experiments were carried out in a special bomb placed on the cylinder head of an air compressor, communication being by means of an automatic valve. The air intake to the compressor is heated electrically, whilst the delivery from the bomb is throttled and passed again to the compressor intake. When the requisite temperature is reached in the bomb the delivery is closed, fuel is injected and the resultant combustion photographed. Depending on the crank angle of the compressor at which injection takes place, the pressure in the bomb will vary, since delivery from the compressor takes place through the automatic valve at the base.

Since the weight of air handled by the compressor is known, the air speed in the bomb corresponding to the charge transfer can be calculated. Various inserts to represent vortex combustion chambers (Ricardo-Comet) or air capacities (Henschel-Lanova) were inserted in the bomb and the flame photographs studied as a function of the air velocity. The results obtained are in general agreement with engine experiments but have the great advantage that the effect of small alterations in the design of the combustion chambers can be quickly ascertained.

The Effect of Gas Inertia on Volumetric Efficiency. (J. Aschenbrenner, Forschung, Vol. 8, No. 6, November/December, 1937, pp. 285-94.) (52/33 Germany.)

The volumetric efficiency of high speed piston engine is markedly affected by inertia phenomena in the inlet pipe.

The author investigates analytically the flow of air in a pipe subjected to a small pressure difference and starting from rest. The paper thus presents a simplified version of previous investigations by the author which covered the more general case of large pressure differences.

The results are directly applicable to engine practice and a worked example shows the application of the formulæ to the case of a high speed motor car engine. The predicted timing of the inlet valve for maximum volumetric efficiency is in good agreement with test results.

An Efficient Silencer for Pipe Lines. (M. Bentele, Forschung, Vol. 8, No. 6, November/December, 1937, pp. 305-11.) (52/34 Germany.)

The silencer described works on the principle of resonance and has the great advantage that it can be tuned to give optimum results after installation.

The theory underlying the design of such silencers is given and verified by experiment. If the resonator chamber is lined with sound absorbing material, the damping curve becomes flatter and the tuning less pronounced.

An example of such a type of silencer as applied to a large roots blower is described and illustrated.

The Effect of Detonation on Engine Stresses. (J. Geiger, Autom. Tech. Zeit., Vol. 40, No. 24, 25/12/37, pp. 614-9.) (52/35 Germany.)

The author investigates the differential equation of motion of a piston/connecting rod system undergoing elastic deformation under the influence of a periodic gas force. He points out that in the case of resonance, the maximum force in the connecting rod will exceed the maximum gas pressure very considerably. In the case of detonation, gas pressure vibrations occur which in the opinion of the author, are of the same order of frequency as those of the piston connecting-rod system. Under these conditions, therefore, bearing pressures much in excess of those usually assumed occur which may explain design troubles associated with "harsh running" Diesel engines.

In conclusion the author refers to experiments by G. Le Mesurier and Stansfield on the vibration of engine structures (North East Coast. Inst. of Eng. & Shipbuilders). These authors measured the actual stresses in the cylinder of an engine under various conditions of operation and found that even a relatively small increase in the rate of application of the gas pressure produced a considerable increase in the peak stress values.

Stresses in Crank Webs—The Disadvantages of Circular Webs. (E. A. Wedemeyer, Autom. Tech. Zeit., Vol. 40, No. 24, 25/12/37, p. 620.) (52/36 Germany.)

By means of model experiments, the author demonstrates that circular webs subjected to bending deformation give rise to unfavourable stress concentrations at the crankpin and journal. This probably accounts for the large number of fractures of shafts with webs of this type.

Square or oval webs on the other hand allow the bending stresses to be equalised, especially if a shallow groove is cut into the web in the neighbourhood of the pin.

Carbon Deposits as Affected by Fuel and Oil. (H. N. Bassett, Autom. Eng., Vol. 28, No. 367, January, 1938, pp. 31-32.) (52/37 Great Britain.)

The author is of the opinion that the presence of anti-oxidants in an engine oil may be expected to reduce the quantity of deposits formed. In confirmation of this view, the results of certain experiments on small air cooled cylinders are quoted which apparently showed beneficial effect of doping the lubricating oil with 1 per cent. of tetraethyl lead. (It should however be pointed out that on account of the relatively large oil consumption of such small units, the beneficial

effects, if any, could be accounted for equally well by the dope affecting the combustion characteristics of the fuel.)

Synthetic Motor Spirits. (J. Hiles, Fuel, Vol. 17, No. 1, January, 1938, pp. 1-2.) (52/38 Great Britain.)

The article refers mainly to the Fischer-Tropsch process, in which a mixture of CO and H_2 is passed over a catalyst. By varying the composition of the mixture, its temperature and pressure as well as the type of catalyst, the nature of the product varies from alcoholic to paraffinic. The yield of paraffin products reaches a maximum at atmospheric pressure, the temperature of the catalyst being of the order of 200° C. This temperature varies with the nature of the catalyst and must be very carefully controlled.

The main disadvantage of the process appears to be the low octane value of the motor spirit obtained which necessitates either doping or blending with benzol. The Diesel oil fraction however has a cetene number of 100 and can be blended with inferior fuel (tar oil). A further objection to the process is the very large space required for the reaction chambers, since the work is carried out at atmospheric pressure. The capital outlay for plant and catalyst is thus heavy.

Pylonol Oil Dope. (Aero Digest, Vol. 32, No. 2, Feb., 1938, p. 83.) (52/39 U.S.A.)

Pylonol is an oil concentrate mixed with a gas oil carrier which evaporates. The remaining 75 per cent. of the solution does not evaporate and will stand a considerably higher temperature than conventional lubricating oils before breaking down. The addition of the concentrate Pylonol does not affect the viscosity characteristics of the parent oil, but on account of its penetrating properties it reduces ring sticking.

It may also be injected into the inlet manifold to loosen valve pistons.

It is claimed that the new dope does not increase engine wear.

A Sound Pressure Level Meter without Amplification. (E. Z. Stowell, N.A.C.A. Tech. Note No. 629, December, 1937.) (52/40 U.S.A.)

The N.A.C.A. has developed a simple pressure-level meter for the measurement of sound-pressure levels above 70 db. The instrument employs a carbon microphone but has no amplification. The source of power is five flashlight batteries. Measurements may be made up to the threshold of feeling with an accuracy of ± 2 db.; band analysis of complex spectra may be made if desired.

Effect of Yaw on Vane Anemometers (R. H. Heald and P. S. Ballif, Bur. Stan. J. Res., Vol. 19, No. 6, Dec., 1937, pp. 685-90.) (52/41 U.S.A.)

The effect of yaw on the performance of three vane-type anemometers was determined in the wind tunnel. Observations were made for angles of yaw within a range of 35 degrees on either side of the zero position. Maximum positive errors of 1, 4 and 5.5 per cent. were found for the three instruments when the angle of yaw was approximately 15 degrees. The magnitude of the error depends on the design.

Plastics as Structural Materials for Aircraft. (G. M. Kline, N.A.C.A. Tech. Note No. 628, December, 1937.) (52/42 U.S.A.)

It is the purpose of this report to consider the mechanical characteristics of reinforced phenol-formaldehyde resin related to the use of such a product as a structural material for aircraft. The data and graphs which have appeared in the literature on this subject are reproduced in this survey as needed to illustrate the comparative behaviour of plastics and materials commonly employed in aircraft construction. (45 references.)

Torsional Stability of Cylindrical Shells. (A. Zahorski, J. Aer. Sci., Vol. 5, No. 2, Dec., 1937, pp. 62-7.) (52/43 U.S.A.)

The design of thin-walled cylindrical shells carrying compressive loads can be greatly simplified by means of diagrams giving the so-called "ellipse of critical stress." For a given form of cross-section and material, only one diagram is necessary. The average critical stress has an elliptical relation to certain dimensionless parameters of the geometry of the shell. Economical shells should have high torsional rigidity examples of the design of equal-legged angles and circular arc sections are given, together with some of the experimental results.

Hydrodynamic Corrosion of Cylinder Liners. (W. Mangold, Z. Metallk., Vol. 29, No. 12, Dec., 1937, pp. 420-2.) (52/44 Germany.)

The contact P.D. between an electrolyte and a metal will depend on the state of motion of the electrolyte and will be markedly different for streamline and for turbulent flow.

The author is of the opinion that examples of cylinder liner corrosion examined by him are due to difference in the state of motion of the cooling water (turbulent at entry and streamline at exit). By suitable guide vanes (especially at entry) these large differences can be smoothed out and the author shows examples of such modified cooling water passages which were free from corrosion troubles.

Relation of Wahl Correction Factor to Fatigue Tests on Helical Springs. (F. P. Zimmerli, Trans. A.S.M.E., Vol. 60, No. 1, January, 1938, pp. 43-4.) (52/45 U.S.A.)

This paper presents the results obtained in an effort to test Wahl's correction factor for spring stresses. Fatigue tests were run on springs of various indexes which were coiled from the same bundle of wire and blued at the same time to ensure uniform treatment. As the results were not uniform, four series of tests were made, with additional tests to demonstrate the inertia effect of the beam of the testing machine and the influence of speed and stroke. With high spring loads the inertia effects of the beam during the down stroke were neutralised by the spring pressure. Stress ranges for the various indexes as obtained in the tests were corrected for (*a*) spring rate, (*b*) stroke, and (*c*) motor speed and the corrected values plotted. From this chart, the conclusion is drawn that the Wahl factor over corrects the stress values for low indexes.

Hot-Pressing Technique for Plywood. (T. D. Perry and M. F. Bretl, Trans. A.S.M.E., Vol. 60, No. 1, January, 1938, pp. 59-68.) (52/46 U.S.A.)

The authors review briefly the history of the cold pressing of plywood with various adhesives, and discuss the development and adoption of hot pressing with thermo-setting synthetic resin adhesives which are more water resistant than the adhesives developed for cold pressing. The various types of domestic and foreign hot presses and their characteristic features are described. It is shown that several factors in the behaviour of wood under heat are common to all known types of resin adhesives; these are the speed of heat penetration through various thicknesses of veneer and the heat losses encountered in practicable bonding periods of time, both differentiated as to core thicknesses, moisture content, and temperature. Specific pressure and wood species are found to have little if any influence on these factors. Another factor is the effect of heat on the tensile strength of wood, which is shown to be relatively unchanged in practicable bonding periods. These phenomena are shown by tables and graphs and are fully described. Other factors individual to the adhesive used, and the characteristics of a resin film, are outlined in tables and are described. The authors predict that the rapidly growing adoption of hot pressing and resin adhesives is widening the plywood market.

Synthetic Resins in Aircraft Construction (Composition Properties, Present State of Development and Application to Light Structures). (K. Riechers, Luftwissen, Vol. 4, No. 8, August, 1937, pp. 235-242. Available at translation T.M. No. 841.) (52/47 Germany.)

The article deals briefly with the manufacture of synthetic resins of various types and the fillers employed.

Synthetic resin glues are receiving extensive application in the manufacture of high quality plywood for aircraft (including propellers).

Aircraft instrument casings made of synthetic resin are also now coming into general use, especially for electrical instruments.

It cannot as yet be predicted whether it will be possible to improve the strength characteristics of these plastics to such an extent that they can be used for aircraft construction. The problem appears to be mainly concerned with obtaining a suitable filler. A propeller made entirely of plastic material (Micarta) has already had a certain measure of success and the obvious advantages of the material from the point of view of mass production have led to intensive research. (Thirteen references.)

The Use of Aircraft for the Dispersion of Hailstorms. (Les Ailes, No. 864, 6/1/38, p. 7.) (52/48 France.)

Various possible means for the dispersion of hailstorms by the use of artillery are discussed. Lately the bombing of hail clouds by means of aircraft has proved successful. Both percussion and smoke bombs have been tried. In the latter a radio active filling is heated by the combustion of the explosive, leaving a highly ionised trail of smoke as the container descends. As the clouds containing the hail are usually highly electrified, this conducting path facilitates discharge and consequent precipitation of the hail. The aircraft dropping these charges would operate at an altitude of the order of 1,000 m. above the hail cloud.

Ice Formation in Clouds in Great Britain. (W. H. Bigg, M.O. Professional Note No. 81, 1937.) (52/49 Great Britain.)

Ice formation constitutes one of the greatest dangers to the regular operation of air routes in certain parts of the world, such as North America and North and North-West Europe. The object of this note is to co-ordinate the information contained in foreign scientific literature on the meteorological condition favourable to ice formation and to give the results of similar investigations carried out in this country.

It appears that the problem of ice formation is very complicated and that considerable meteorological experience will be required if the pilot has to rely on navigation alone in order to avoid disaster.

For this reason various devices (thermal, mechanical, chemical) have been developed to prevent a dangerous accumulation of ice on the aircraft. More experience will be required to decide which of these means is likely to prove the best practical solution.

Geometrical Considerations on Picard's Method of Iteration. (Th. Zech, Z.A.M.M., Vol. 17, No. 6, Dec., 1937, pp. 341-2.) (52/50 Germany.)

First, the solution by iteration of the equation $x = \phi(x)$ is first considered and a geometrical formulation of the condition for its convergence is given, the usefulness of which is shown by applications, *e.g.*, to Newton's method of approximation. Picard's method of solving differential equations by successive approximations is next illustrated geometrically. In order to ensure a quick convergence of the process we are led quite naturally to Lipschitz's condition.

Mechanical Solutions of Algebraic Equations. (H. C. Hart and I. Travis, J. Frank. Inst., Vol. 225, No. 1, January, 1938, pp. 63-72.) (52/51 U.S.A.)

The paper describes a machine for determining the real and complex roots of higher degree algebraic equations. The principle of operation is found in the correspondence between sine wave quantities and complex numbers. The particular machine is designed for equations of the eighth degree, and finds all the roots with engineering accuracy in the space of a few minutes.

Though primarily designed for facilitating electric network calculations, the machine should find utility in other fields of applied mathematics as well.

Flight Speed of Birds. (M. T. Cooke, United States Department of Agriculture, May, 1937, Circular No. 428, pp. 1-13. Article available in R.T.P. (Abstracts).) (52/52 U.S.A.)

This most interesting pamphlet gives the flight speed of about 100 birds, mostly North American species. A bibliography of 86 items completes the work and gives the authorities for the figures quoted. In the majority of cases, the observer travelled in a motor car and the bird's speed is estimated from the speedometer. In about a dozen cases the bird is timed from an aeroplane and several good observations are recorded from trains. Only very few theodolite measurements are included.

From the author's remarks and the table of speeds, the following general conclusions may be drawn:—

1. A speed of 60 m.p.h. is exceptional and only reached by a few species (plover, pheasant).
2. For most of the birds listed, the speed is of the order of 30 m.p.h.
3. A falcon striking its prey appears to dive at well over 100 m.p.h. Such cases are, however, very difficult to measure.
4. Few birds fly at altitudes above 3,000 feet and none above 5,000 feet.
5. Birds do not like a tail wind and appear to give the best performance with a side wind.
6. The stability in turbulent air differs enormously in different species. In one case crows were unable to return to their nest whilst a flock of geese were apparently unaffected.

A New Method of Infra-Red Photography. (M. Czerny and P. Mollet, Phys. Zeit., Vol. 38, No. 23, 1/12/37, pp. 1008/1010.) (52/53 Germany.)

The process depends on the evaporation of extremely thin layers of paraffin oil deposited on a celluloid film (0.1 μ thick), backed with a thin layer of aluminium.

The thermal effects of the infra-red radiation are thus converted into interference colour changes of the film which can be photographed on a normal plate.

The new process can be used for much longer wave lengths than is possible with red sensitised plates, which generally cannot be used beyond 1.3 μ.

For the shorter wave length of the infra-red spectrum (neighbourhood of 1.05 μ), the direct photographic method is however to be preferred since it requires much shorter exposure times (ratio of 25 to 1).

Dimensional Changes in Aerial Photographic Film and Paper. (R. Davis and E. J. Stovall, Bur. Stan. J. Res., Vol. 19, No. 6, Dec., 1937, pp. 613-37.) (52/54 U.S.A.)

Results of a study of dimensional changes in aeromapping photographic film and papers under controlled conditions are presented. Both films and papers are subject to a shrinkage from processing. These materials are hygroscopic, con-

sequently their dimensions change with the varying moisture content of the air. Dimensional changes from both processing and moisture content are least in the machine direction, that is, along the roll. Films continue to shrink with time, because of a loss of solvents and plasticizer. This shrinkage is illustrated by accelerated ageing tests at 120°F. covering a period of 32 days. Two new instruments developed for measuring film shrinkage are described. A reduction of differential shrinkage in the final print or duplicate negative can be obtained by crossing the machine directions of the negative and printing material during exposure.

New Test for Dimensional Changes in Offset Papers. (C. G. Weber, M. N. V. Geib, Bur. Stan. J. Res., Vol. 19, No. 6, Dec., 1937, pp. 665-73.) (52/55 U.S.A.)

Change of dimension of paper is a serious factor in many of its uses, particularly in multi-colour offset printing where changes of dimensions cause the greatest difficulty—misregister of prints. The changes are caused by variations in the relative humidity of the surrounding air. To predict the relative constancy of dimensions of papers in use, a method was devised for determining the expansivity of paper with variations in relative humidity. Specimens of paper approximately 24 inches in length are mounted under constant tension in a cabinet in which humidity is controlled by salt solutions. Changes of length of the paper are measured by means of an optical lever, with a sensitivity of 0.00025 inch and the humidity and temperature inside the cabinet are determined with a wet- and dry-bulb hygrometer. The data thus obtained checked closely with those obtained by measuring specimens on a flat surface with a micrometer rule and were much more conveniently obtained and more reproducible.

Decibels and Phons. (Nature, Vol. 141, No. 3562, 5/2/38, p. 237.) (52/56 Great Britain.)

The decibel is a unit for specifying changes in intensity, power or energy and not a direct measure of the absolute value of these quantities. Decibels are not additive, since they measure the ratio on a logarithmic scale. Two similar sounds of intensities, I and I^2 are said to differ in intensity by n decibel, if $N = 10 \log_{10} I/I_0$. Therefore a tenfold increase in the intensity corresponds to a change of 10 decibels, a hundredfold to 20 decibels, and so on. One decibel corresponds to an increase of intensity or energy in the ratio of approximately 5/4, and three decibels to a ratio $(5/4)^3$. Hence, doubling the intensity corresponds to a change of 3 decibels. When a sound is said to have an intensity of n decibels, it is implied that it is compared with some standard intensity which has been selected as zero level. The international standard adopted is an acoustical pressure of 0.0002 dyne/cm.^{2}, this being near the threshold of hearing for frequencies of the order of 1,000/sec. The decibel scale is purely physical and does not depend on the characteristics of the ear, which assesses "loudness." For measuring loudness, a pure reference tone of constant frequency (1,000/sec.), but variable intensity has been adopted. The intensity of this is varied till it produces the same sensation of loudness as the noise under investigation. If the intensity of the reference tone above the zero level is n decibels, the noise is said to have a loudness of n phons. For sounds of medium frequency and moderate intensity a phon happens to correspond roughly to the smallest difference detectable by alternate listening under ordinary conditions.

Measurement of the Total Radiation of Steam and CO_2 in Mixtures with Non-Radiating Gases at Temperatures up to 1,300°C. (E. Eckert, Forschungsheft, No. 387, November/December, 1937.) (52/57 Germany.)

The total radiation of H_2O and CO_2 mixed with N_2 was measured at temperatures up to 1,300°C., the layer of gas varying from 10 cm. to 3 m. In the case

of CO_2 the radiation only depended on the product of the partial pressure of the radiating gas and thickness of layer (Beer Law). This law, however, does not hold in the case of H_2O.

The results of the experiments are applied to the calculation of the radiation heat transfer coefficients in boilers and engine cylinders. In the case of a normal water tube boiler, the heat transfer by radiation is of the order 15 K. cal./$m_2$hoC. and reaches about ten times this value at the beginning of the expansion stroke of an Otto engine. From this it would appear that the heat loss due to radiation amounts to 15-25 per cent. of the total heat loss (radiation and conduction) at this part of the stroke. This value is very much higher than is normally assumed.

Heat Transfer by Radiation and the Calculation of Grid Temperatures in Wireless Valves. (S. Wagner, Forschung, Vol. 8, No. 6, November/December, 1937, pp. 314-5.) (52/58 Germany.)

The general problem of determining the individual temperature of n bodies in thermal equilibrium under the influence of radiation only can only be solved under certain simplifying conditions.

The author sub-divides the total radiation received by any one body into two parts, one of which being the radiation received directly, *i.e.*, without previous reflection, whilst the second is the remainder. In order to render the resultant equations tractable, the author further assumes that for each body of the system:

(*a*) The surface temperature is practically constant.

(*b*) The normal component of the temperature gradient along the surface is practically constant.

The resulting solutions are verified experimentally for the case of four plates, one of which can be heated electrically.

In the case of grid temperature in valves, matters are complicated since condition (*b*) above is not fulfilled. The author shows how the practical grid can be replaced by an " idealised " version amenable to mathematical treatment. The final calculated values differ by less than 4 per cent. from measured values.

A Thermionic Trigger. (O. H. Schmitt, J. Sci. Inst., Vol. 15, No. 1, January, 1938, pp. 24-6.) (52/59 Great Britain.)

A simple hard valve circuit is described which provides positive off-on control with any desired differential from 0.1 V. to 20 V. Less than 10^{-6} amp. is required at the input, but up to 20 m.a. at 200 V. is available in the output. Either positive or negative control is possible. The operation cycle occupies about 10 μ sec. Applications to cathode ray oscillography, to " thermostating " and to lighting control are illustrated.

The Ultra Short Wave Guide Ray Beacon and its Application. (E. Kramar and W. Hahnemann, Proc. Inst. Rad. Eng., Vol. 26, No. 1, January, 1938, pp. 17-44.) (52/60 U.S.A.)

PART I.—Proceeding from the present state of the art of air navigation in the U.S.A., and in Germany, the ultra short wave instrument landing system in Europe is described. Mention is made of the experience gained in the operation of the beacon. In the operation of neighbouring beacons, disturbed zones will occur which, by choosing the proper frequency spacing and the proper selectivity of the receivers, may be restricted to such an extent that they will not impair the use of radio beacons in any way. These problems are discussed more in detail.

PART II.—The propagation of ultra short waves is treated on the basis of the theory of combining reflection and diffraction on the earth with respect to their

application to long-range navigation. It results that for a fixed distance and flying height an optimum wave length exists allowing the aeroplane to cover ranges of 250 km. and more.

Examples are given for producing four beams in any desired direction and for introducing the landing beacon in the long range navigation system.

Finally the properties and advantages of an ultra short wave system of navigation are considered in comparison with the use of long wave beacons.

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the Library of the Society.

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AERODYNAMICS.

471,342. *Method and Devices for the Obtainment of Fluid Streamline Contours.* Huet, A., 48, Avenue du President Wilson, Paris, France. Convention date (France), Aug. 10th, 1935.

It is proposed to obtain a fluid streamline round a moving body by the formation of a fluid streamline body surrounding the movable body by placing in front of the movable body of a number of deflecting surfaces disposed to deflect the air from the movable body, the surfaces containing between them and the body diverging channels or orifices for admission through which passes part of the fluid. There is also a rear apparatus formed by convex surfaces which regulate the flow of the fluid streams, the front and rear apparatus being disposed so as to ensure the stability of the fluid streamline body.

AEROPLANES—CONSTRUCTION.

470,698. *Improved Method of Construction of Structural Work such as the Bodies of Motor Vehicles.* Park, Ward and Co., Ltd., 273, High Street, Willesden, London, and Roberts, A. T., 62, Devonshire Street, Piccadilly, London, W.1. Dated Nov. 19th, 1935. No. 32,066.

It is proposed to construct the bodies with pillars, cross-bracings and other members constituting skeleton framework of box section by assembling two or more lengths of light gauge metal with flanges adapted for inter-engagement so that when the section is formed the flanges are external to the structure, crumpling together and then wrapping or bending them together over on the adjacent side wall of the structure. The crumpled margins may be welded.

469,904. *Improvements relating to Aeroplanes.* Stieger, H. J., 54, Bathgate Road, London, S.W.19. Dated Feb. 4th, 1936. No. 3,346.

In order to vary the wing area of aeroplanes during flight, it is proposed to use an auxiliary wing which can be detached during flight, this wing may be the upper wing of a biplane. At the moment of release a small change of incidence is made

to the detachable wing. Other parts, such as the undercarriage, may also be jettisoned.

469,960. *Improvements in or relating to Hoods for Aircraft Cockpits or Cabins.* Bristol Aeroplane Co., Ltd., and Frise, G., both of Filton House, Bristol. Dated Feb. 5th, 1936. No. 3,538.

It is proposed to use a cockpit hood which is telescopically retractable into a cockpit. Preferably the hood is supported on a number of pillars slidable in guides and springs are arranged to extend it. It may also be operated by a rack and pinion. Locks are provided where necessary to retain the hood in a desired position.

474,065. *Improvements in or relating to Surfaces Adapted to be Displaced in a Fluid Medium.* Fauvel, C., and Coltel, H., Les Bengalis Cazaux (Gironde), France, and Boid de la Ste. Genevieve, Quai le Turleries, Paris, France, respectively. Convention date (Belgium), Jan. 17th, 1935. Specification not accepted.

In order that such surfaces as aeroplane wings may have the stresses in them reduced and so that these stresses do not vary materially under the effect of variations of the angle of incidence, it is proposed to use wings which can have their fore and aft sections varied in accordance with variations of incidence, etc., so as not to vary the position of the centre of pressure. Several ailerons may be used operating at different inclinations increasing towards the wing tips.

471,124. *Improvements in or relating to the Construction of Wings, Fuselages and other Aircraft Bodies.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Weybridge, Brooklands Road, Weybridge, Surrey. Dated Feb. 27th, 1936. No. 5,886.

In the construction of aircraft bodies it is desirable to be able to vary the form of construction so that a body of one form of construction can be used for a body of another form of construction with a minimum of change. It is also desirable to be able to complete the attachment of fittings and equipment before the fuselage is completely assembled. To enable this to be done the body is built up of a number of component parts, including a series of spars or booms spaced apart from each other and surface components with fabric or plating and reinforcing members on the interior of the covering, the said parts being built up as units.

471,514. *Improvements relating to the Construction of Aircraft and the Like.* Stieger, H. L., 54, Bathgate Road, London, S.W.19. Dated Feb. 4th, 1936. No. 3,347.

A wing of an aeroplane built up of previously constructed members, namely, an upper and lower member, each of which forms part of the skin and has structure projecting internally for attachment together. Additional skin members may be used to close openings in the assembled component. Fuselages, floats, etc., may be constructed in a similar manner.

471,123. *Improvements in or connected with Aircraft Frame Structures.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Feb. 27th, 1936, No. 5,885, and Jan. 22nd, 1937, No. 1,920.

This specification refers to the construction of wings, fuselages, etc., in which tubular booms are employed. The booms are formed of tubes of uniform size arranged in spanwise sections of multiple side-by-side tubes in the root and a decreasing number of tubes beyond the root. The tubes may be varied in wall thickness. The booms are serrated to engage with fishplates having faces curved to interlock.

472,839. *Improvements in or connected with the Construction of Wings for Aircraft.* Supermarine Aviation Works (Vickers), Ltd., and Mitchell, R. I., both of the Company's Works, Woolston, Southampton, Hampshire. Dated March 31st, 1936. No. 9,517.

It is proposed to combine the fuel tanks with the wing structure. The wing may be constructed with upper and lower booms with a shaped tank attached to them having a part of the tank extending between the booms and acting as the spar web. The tanks may form the nose portion or a more rearward portion of the aerofoil. It is claimed that the arrangement effects a considerable weight saving.

472,366. *Improvements in Removable Roof for the Cockpit of Aircraft.* Saulnier, R., 5, Rue de Monceau, Paris, France. Convention date (France), Dec. 27th, 1935.

The roof proposed is intended to be opened normally by sliding and is also capable of being immediately detachable from the machine, a provision in case of accident. Further, if the roof cannot be detached as when the machine is upside down on the ground, there are doors in the side which are arranged to open in the case of such an accident. The roof movements can be operated from inside the cockpit.

475,433. *Improvements in or relating to Aircraft having Folding Wings.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Bolton, F., 22, Shanklin Road, Southampton, Hants. Dated July 8th, ——. No. 18,953.

An object of this specification is to enable the overall width of an aircraft when the wings are folded to be reduced. The ailerons or flaps are permitted to drop automatically when the wings are folded and are raised automatically when the wings are spread.

475,493. *Aeroplane Construction.* Barnhart, G. E., 407, Waldo Avenue, Pasadena, California, U.S.A. Dated April 16th, 1936. No. 10,680.

It is proposed to use in combination an aerofoil with a vane member formed of two hinged portions pivotably secured at the end of one section of the aerofoil and a pilot flap arranged in advance of the vane member for controlling the amount of air impinging thereon. The aerofoil may have a single vane member in the rear of the first vane member, the single vane being hinged to the aerofoil at a location such that the air stream modified by the first vane member strikes the single vane member.

474,003. *Aircraft Wings.* Sir W. G. Armstrong Whitworth Aircraft, Ltd., and Lloyd, J., both of Whitley, Coventry, Warwickshire. Dated July 7th, 1936. No. 18,821.

It is proposed that the wings of a monoplane may be folded by dividing each wing transversely into at least three sections which are hinged together in such a way that the outer sections of the wing can be folded to lie substantially horizontally alongside one another adjacent the inner section, detachable joints being provided for holding the sections extended

476,133. *Improvements in Streamlined Tie Rods for Aircraft and like Members and Method of Making the Same.* Flynt, L. W. G., 24, South 6th Street, Newark, New Jersey, U.S.A. Dated Sept. 29th, 1936. No. 26,402.

The proposed tie rod has circular ends and a middle portion of streamline shape, one section merging into the other without appreciable variation in sectional area. It is proposed that they shall be manufactured from blanks of symmetrical form and a section formed by the combination of a circle and a streamline shape.

474,241. *Improvements in Aeroplanes.* De Jong, A., Vlaardingen, Holland, and Volpert, 4, Schiedam, Holland. Dated April 27th, 1936. No. 11,976.

It is proposed to construct an aeroplane with a deep sectioned wing extending across the top of the fuselage so that the leading edge and the upper surface is continuous. There is a large air inlet opening forwards in the nose of the fuselage which is connected to the suction side of an air pump, the air being discharged to transverse slots in the leading edge of the wing above the fuselage, or near to it. Various arrangements of the pump and slots are described.

AEROPLANES—GENERAL.

470,650. *Improvements in or relating to Aircraft.* Airspeed (1934), Ltd., and Tiltman, A. H., The Airport, Portsmouth. Dated Feb. 25th, 1936. No. 5,618.

It is proposed to produce an aeroplane in which the tailplane is carried by booms from the wings and in which the pilot and crew are contained in a nacelle arranged to act as a fin. This nacelle is carried on the rear fin.

469,557. *Improvements in or relating to Composite Aircraft.* Mayo, R. H., 55, Pall Mall, London, S.W.1, Short Bros. (Rochester and Bedford), Ltd., and Clark, A., both of Seaplane Works, Rochester, Kent. Dated Jan. 27th, 1936. No. 2,488.

The locking means between the two aircraft may comprise a hook pivoted to the lower component, a latch pivoted to the upper so that the hook exercises a progressively increasing turning movement on the latch as the separating force increases. The safety device is released when the separating force reaches a predetermined limit. The locking means may include release levers connected to override the pilot's controls and the locking means may also provide a member arranged to displace progressively as the separating forces increase and this may be arranged to give a visual indication to the pilot's by electrical means.

469,739. *Improvements in or relating to Flying Machines.* Pouit, R. J., 1, Rue Edouard Branly, Issydes, Moulmeaux (Seine), Paris. Convention date (France), Jan. 28th, 1935.

In an aeroplane fitted with brakes on the landing gear, arrangements are made so that when the aeroplane lands in the flying position the lift of the aerofoils is destroyed or diminished so as to prevent capsizing so that much higher breaking torques can be used. The brakes are inter-connected with wing flaps which are raised so as to destroy lift.

469,094. *Improvements in Flying Machines.* Société des Moteurs Salmson, 68, Rue Pierre Charron, Paris, Seine. Convention date (France), Nov. 23rd, 1934.

It is proposed to pivot wing flaps on an axle situated below the lower part of the wing. It is claimed that with this arrangement the controls are simple, that the trailing edge remains nearly in the vertical plane of the wing trailing edge and that the hinge moment is reduced.

469,149. *Improvements relating to Wing Flaps for Aircraft and Their Control.* Phillips and Powis Aircraft Co., Ltd., of Reading Aerodrome, Woodley, Reading, Berkshire, and Miles, F. G., of the same address. Dated April 14th, 1936. No. 10,754.

The proposed arrangement consists of wing flaps in two sections interconnected for movement in opposite directions so that one area will act as a servo to operate or help to operate the other, the servo area and interconnection being

chosen so that it only becomes effective at a chosen phase of the operation of the remainder. The operating means has two operating positions corresponding to a partially operative and wholly operative position of the flap.

470,923. *Supporting Surface for Flying Machines.* Kooll, J., 22, Enderstrasse, Breslau 10, Germany. Dated Feb. 24th, 1936. No. 5,518.

The wing proposed has a rear flap attached on the underside of which is a secondary flap of the split type. For high speed flight the flaps are arranged to give the standard wing profile. For starting, the main flap is displaced to the rear and pulled down. For landing, the main flap is displaced to the rear and the auxiliary flap is pulled down and also displaced rearwards. Several alternative forms of a wing having these characteristics are described and details of the proposed construction are given.

470,528 *Improvements in Aircraft.* Budig, F., 37, Quais des Grandes, Augustins, Paris VI, France Dated June 25th, 1936. No. 17,633.

It is stated that, in an aeroplane wing, the airstream meeting the leading edge and thereby split into two streams be not deflected away from the surface of the plane by eddies. Accordingly, it is proposed to fit a step under the wing close to the leading edge tapering away into the leading edge. This step is adjustable and may be of the form of a flap hinged at the leading edge itself.

471,946. *Improvements in or relating to Aircraft.* Delanne, M. H., 17, Rue Servandoni, Paris, France. Convention date (France), July 4th, 1935.

An aeroplane having a rear supporting plane in staggered relation with the front plane has the tailplane provided with a drift plane on each side of the fuselage fixed perpendicularly to the rear plane and parallel to the axis of the fuselage control surfaces being hinged to the drift plane for steering. The rear supporting plane co-operates with the front plane to increase support and mobility.

471,656. *Improvement in Aeroplanes.* Lindstrom, G. E., Bergsgatan 19, Stockholm, Sweden. Dated Jan. 29th, 1937. No. 2,631.

The proposed aeroplane has a wing or wings arranged so as to be immersed in the slipstream from the propellers. The wings have a small fixed portion, the rest being flexible and can be bent down sufficiently to allow the slipstream to lift the machine vertically.

472,642. *Improvements in or relating to Aeroplanes Convertible from Monoplanes to Biplanes or Vice-versa.* Tommeo, F., 78, Via XX Settembre, Turin, Italy. Dated March 26th, 1936. No. 8,981.

The arrangement proposed consists of a monoplane with planes which can be split so as to form two planes, by means of, say, a screw gear. Several differing methods of bracing the machine, both as a monoplane and a biplane are described.

472,546. *Improvements in or relating to Aircraft.* Mayo, R. H., 55, Pall Mall, London, S.W.1. Dated March 24th, 1936. No. 8,758.

A composite aircraft is proposed, comprising two aircraft mounted one on top of the other, locking means to secure them together which are releasable to enable detachment to be carried out in flight, and a flexible connecting link between them which continues to connect them after detachment has taken place. This link may be a tube through which fuel can be pumped.

473,682. *Improvements in or relating to Aircraft.* Mainguet, H., 10, Rue Garanciere, Paris, France. Convention dates (France), Jan. 13th, 1935, and June 22nd, 1935.

It is proposed to arrange the wings of aircraft so that the air before being attacked is deviated upwards so that the reactions on the wings are deviated and the wings become hyper-sustaining and even propelling. The machine has wings of decreasing depths arranged one in front of the other, the wing of least depth being in front with a negative angle of incidence.

475,218. *Improvements in or relating to Aircraft having Folding Wings.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Flt. Lieut. L. M. Hilton, Ravelston, Pinner Hill, Middlesex. Dated Nov. 6th, 1936. No. 30,281.

The wings of an aircraft are locked in flying position by locking pins inserted through registering apertures in overlapping eyes or the like on the relatively fixed and foldable portions of the wing, the pins being movable oppositely in pairs by screw action. It is proposed to move these pins by jointed rods connected with an intermediately disposed pair of members arranged to be rotated concurrently by a common ratchet and pawl device.

474,659. *Improvements in or relating to Aeroplanes.* Huley, P., Bear Creek, Dawson, Yukon Territory, Canada. Dated March 16th, 1937. No. 7,745.

The apparatus described is called a glider, but is shown in the illustration to be fitted with an airscrew and pedalling gear. The machine is described as having an elongated rectangular frame, a wing across the top thereof, two main posts depending from the wind carrying the landing gear, and a cabin constructed about the posts.

AIRSHIPS.

475,587. *Improvements in and relating to Flying Machines.* Glaser, M. A., 24, Rue de la Sabliere, Asnières (Seine), France. Convention date (France), Oct. 24th, 1935.

The arrangement claimed consists of a dirigible and a nacelle, the latter having an airscrew mounted so that its axis can be included in any direction from the normal to the vertical, the airscrew being underneath the nacelle. The mounting may be so designed so that the engine and the airscrew may be inclined together.

AIRSCREWS.

472,318. *Improvements in or relating to Aircraft Propulsion.* Maina, J., 35, Maybury Mansions, Marylebone Street, London, W.1. Dated March 18th, 1936. No. 8,108.

This is an arrangement by which two concentric propellers arranged close to each other may be driven in opposite directions by a single engine. The propellers are driven by one shaft inside another and there is a driving bevel gear attached to the central shaft, a driven gear attached to the tubular shaft and intermediate gears carried by a spider located in position on the central shaft. The central shaft is arranged to have a predetermined amount of spring in torsion, the crankshaft being coupled to one end of this shaft. The spring torque element may consist of a star-like member secured to the central shaft provided with radial blades engaging slotted bushes carried by a drum connected by gearing with the power unit.

AMPHIBIANS.

475,057. *Improvements in and connected with Control Mechanism for Amphibian Aircraft.* Perry, R., 30, Oak Street, Manchester 4, Lancaster. Dated May 11th, 1936. No. 13,357.

The aircraft proposed is stated to be capable of travelling on land, water or air, and has land wheels, a water propeller, a rotary wing and an airscrew. The arrangement described consists of means for connecting the engine to the various elements so that they may be driven as required.

BOMBS AND BALLISTICS.

475,377. *Gun Turret, Particularly for Aircraft.* de Gavardie, P. H. E., 65, Rue Nicolo, Paris 16°, France. Convention date (France), June 20th, 1936.

The proposed gun turret is a movable unit supported by a universal suspension at approximately its centre of gravity. Aiming is accomplished in any direction of space solely by hand-operated rotation about the two axes of the inversal suspension. The weapon is fixed rigidly to the gunner's cabin. The two movements of the unit about the two axes are operated by two independent cranks preferably mounted one on each side of the gunner's seat. The unit may be fixed by simultaneous braking on the two cranks.

CATAPULTS.

470,767. *Improvements in Electro-Magnetic Machines with Longitudinally Moving Armatures.* Sander, N., 33, Hook Road, Surbiton, Surrey. Dated Feb. 20th, 1936. No. 5,093.

This specification refers to electrically operated catapults and it is proposed to dispose along the runway a laminated iron core with a squirrel cage winding and to fit the carriage with a laminated armature with a polyphase winding. The resistance of the winding along the track being varied so as to produce the desired acceleration. A gap is provided in the live rails bridged with a polyphase transformer which serves to reduce and reverse the current beyond the gap so as to retard the carriage.

CONTROL OF AIRCRAFT.

476,673. *Aeroplane Wing Flaps.* Gray, W. E., 8a, Bank Parade, Edgware, Middlesex. Dated March 12th, 1936. No. 7,490.

The proposed flap may be divided along its span by a hinge, the rearward portion is arranged to be angularly adjusted with regard to the rest so that it can be turned out of the airstream into the shelter of the wake so as to overbalance the flap with a view to its operation.

475,163. *Aeroplane Wing Flaps.* Gray, W. E., 8a, Bank Parade, Edgware, Middlesex. Dated May 12th, 1936. No. 13,456.

It is proposed to use a slotted flap provided with a forwardly extending piece hinged to its nose, arranged so that when the flap is moved the front edge of this piece moves downward. When in normal position the piece lies flush with the wing.

471,583. *Improvements in and relating to Dual Control Devices of Aircraft or of Other Machines.* D'Oplinter, J. G. M. J. de W., 73, Roger Vanden Driessche Wolurve, St. Pierre, Belgium. Dated Feb. 15th, 1937. No. 4,472.

The dual control is of the type in which the wheel can be swung from one pilot to the other during flight, it is proposed also to swing the rudder bar, the change over of this control being obtained automatically by swinging over the wheel control.

473,379. *Improvements in or relating to Lifting Surfaces of Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Brown, A. C., 109, Cleveland Road, West Ealing, London, W.13. Dated Aug. 20th, 1936. No. 22,949.

This specification describes a type of wing flap consisting of two portions, the first, consisting of a flap which can be moved rearwardly and downwards, the second consisting of a split flap attached to the rear of the first flap. Three flying régimes are contemplated. Normal flight with both flaps folded. Taking off with the first flap only extended. Landing with both flaps extended.

472,845. *Improvements in and relating to Control Surfaces for the Wings of Aeroplanes.* Martin, J., Higher Denham, Uxbridge, Middlesex. Dated April 3rd, 1936. No. 9,897.

This arrangement applies particularly to lateral control surfaces projecting beyond the wing tips of an aeroplane, the surfaces being capable of angular adjustment by the pilot. The angular movement takes place about an axis coaxial with a main wing spar and the forces produced are transmitted directly to the spar. The arrangement may be used in conjunction with normal ailerons and it is stated that added efficiency may be obtained by adding a flap to the control surface, the angle of the flap being varied with that of the surface itself.

472,567. *Improvements in Aerofoils with Variable Camber.* Luttman, H. C., 1, Hooley Range, Heaton Moor, Stockport, Cheshire. Dated Aug. 31st, 1936. No. 23,758.

It is proposed to place a subsidiary member behind the rear spar of a wing and to connect the two together by links pin-jointed at their ends. The rib linkage may comprise two sets of units in one series. There are units consisting of two cross links pin-jointed at their ends and in the other two crossed links picking up alternative pin-joints. The linkage is covered with a skin which may be flexible or composed of hinged panels attached to the mechanism of links.

475,500. *Aeroplane Wing Flaps.* Gray, W. E., 8a, Bank Parade, Edgware, Middlesex. Dated May 16th, 1936.

The split trailing edge flap proposed is supported from the wing structure by a pivoted link running from the wing to a pivot on the flap some distance from the leading edge. It is guided by an additional support near the leading edge consisting of a roller working in a track so shaped that the aerodynamical load on the flap is substantially balanced by the force on the link and the reaction between the track and the roller.

476,258. *Improvement in the Method of and Means for Controlling Aircraft.* Vickers Aviation, Ltd., and Ellis, D. L., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated June 6th, 1936. No. 15,890.

The wing is provided with an opening or recess in its upper surface near its trailing edge in communication with another opening in its upper surface at a point where a larger depression will occur in flight. A method of opening or closing the communicating passage is used so as to enable the pressure distribution to be changed at will.

CONTROLS.

469,906. *Improvements in or relating to Liquid Pressure Remote Control Systems.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1, and Brown, F. V., of the same address. Dated Feb. 5th, 1936. No. 3,529.

In the case of double acting hydraulic control systems it is proposed to arrange for an alternative pipe system if one of the component parts of the system become

inoperative. The proposed system may comprise a reversible flow master unit, a double acting slave unit, a pair of normal pipe lines, a two-way manually actuated valve, a pressure controlled valve and an auxiliary pipe line.

470,088. *Improvements in Fluid-Operated Piston Apparatus.* Mery, F., 15, Via Giovanetti, Turin, Italy. Dated Feb. 3rd, 1936. No. 17,032.

This specification refers to an apparatus consisting of a piston working in a cylinder having a longitudinal slit. The piston has an arm extending outward through the slit and there is a closing member for the slit. It is proposed to use a number of cylinders, the edges of the slits may have parallel grooves and the slit closing member may be of U form so that the flanges may enter the grooves. The arrangement is stated to be suitable for aeroplane catapults.

ENGINES.

469,614. *Improvements in or relating to the Mounting of Internal Combustion Engines.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Forsyth, A. G., "Venlaw," Burdon Lane, Cheam, Surrey. Dated Jan. 31st, 1936. No. 3,003.

The crankcase of an engine is carried from each side by two pairs of triangulated members. In order to provide for expansion or contraction of the crankcase the connections may be flexible. The engine crankcase may be strengthened by a pair of bolts or tie rods passing through transversely of the plane of conjunction of its value, the supporting elements for the engine being connected to these ties.

469,615. *Improvements in or relating to Power Plants for Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Forsyth, A. G., "Venlaw," Burdon Lane, Cheam, Surrey. Dated Jan. 31st, 1936. No. 3,004.

It is proposed that the parts associated with the engine, such as cooling system, oil cooling system, supercharging system and means for preheating air supply are formed integrally with, and attached to, the crankcase of the engine itself, the said crankcase above is attached to the fuselage.

474,912. *Improvements in Means for Operating Control Gills of Engine Cowlings.* Short Bros. (Rochester and Bedford), Ltd., and Parks, A. G., of Seaplane Works, Rochester, Kent. Dated May 9th, 1936, and Feb. 19th, 1937.

This arrangement is stated to be particularly suitable for operating the sprocket which is a standard part of the N.A.C.A. cowling equipment. It is proposed to operate this sprocket by means of a hydraulic ram mounted coaxially through a nut and a high pitched thread, hence converting the reciprocating movements of the ram into rotary movements.

475,123. *Improvements in Cowled Motive Power Plants.* Société Francaise, Hispano-Suiza, Rue du Capitaine Guynemer, Bois-Colombes (Seine), France. Convention date (Belgium), Dec. 24th, 1935.

It is proposed to cool liquid-cooled engines by means of radiators of arcuate cross section which surround the crankcase on the side opposite to the cylinders. It is claimed that streamlining is improved by this arrangement and drawings are given showing various methods by which this streamlining can be carried out.

475,124. *Improvements in Resilient Suspensions for Aircraft Engines.* Société Francaise Hispano-Suiza, Rue du Capitaine Guynemer, Bois-Colombes (Seine), Paris. Convention date (Belgium), April 27th, 1936.

It is pointed out that resilient mounting of an engine makes it necessary to use a design of mounting in which the engine crankcase is not part of the struc-

ture. It is therefore proposed to use a resilient suspension for aircraft engines in which the load supporting and taking members, between which are interposed the cushioning members, are so located that they can be securely braced by means of rigid members subjected only to tensile or compression stresses. There may be a cradle structure attached to the engine and a cantilever frame connected to the aircraft with resilient members between them.

470,460. *Silencer for the Discharge of Internal Combustion Engines, and Particularly Those of Aircraft.* Aldo Guglielmetti, 39, Via Odavia, Rome, Italy, and Stipa, N., 9, Via Rovenna, Rome, Italy. Convention date (Italy), Feb. 12th, 1935.

The silencer proposed is of the form of an open-ended tube placed so that the tube is traversed by an air current in flight. The walls of the tube have substantially the shape of a venturi, the exhaust gas being discharged in the form of an annulus close to the smallest diameter of the tube. It is claimed that the reduced pressure helps the discharge of the gas. In the silencer described the exhaust gas is conveyed to an annular expansion chamber before being discharged, the expansion chamber being bent back on itself S-fashion.

470,473. *Improvements relating to Exhaust Silencers for Engines.* Blanchard, J. G., 1, Ravenna Road, Putney, London, S.W.15. Dated Feb. 14th, 1936. No. 4,512.

It is proposed to use a number of silencers in parallel placed within a streamlined part of an aircraft. The various units receiving gases form a common inlet and discharging them preferably to a common outlet.

471,156. *Improvements in and relating to Aircraft and Exhaust Systems Therefor.* Martin, J., Higher Denham, near Uxbridge, Middlesex. Dated Feb. 27th, 1936. No. 5,876.

It is stated that orifices for the discharge of exhaust gas and the ejection of exhaust gas increase the resistance of aeroplane fuselages. It is therefore proposed to use exhaust pipes which extend within the fuselage or nacelle contour, the gases being discharged at the tail end, and there are means provided for conveying a cooling current of air along the pipes. The manifold itself is surrounded with a pipe between which there is a flow of air, this air being mingled with the exhaust gas and discharged into the exhaust pipe itself.

471,177. *Improvements in Exhaust Discharge Arrangements for Internal Combustion Engines.* de Paravicini, T. P., The Old Manor, Abbotts Ann, Andover, Hampshire. Dated Nov. 30th, 1935. No. 33,282.

It is proposed to utilise exhaust gas to provide a propulsive effect in aircraft. The gas is discharged into a rearwardly projecting manifold or manifolds having the orifice or orifices shaped as tapered nozzles so as to produce a pressure of one pound per square inch above the atmospheric pressure. The gases are discharged at, at least, twice the speed of the external air stream so as to cause a forward thrust. They may be discharged in the boundary layer of the air flowing over the aircraft so as to smooth out eddies.

471,371. *Cooling of Aircraft Engines.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and De Paravicini, The Old Manor, Abbotts Ann, Andover, Hants, England. Dated March 8th, 1936. No. 6,731.

It is proposed to use a new means for controlling airstreams flowing through ducts housing the cooling surfaces of aircraft engines. These means comprise one or more adjustable flaps or shutters hinged at the rear edge and adapted

as moved about their hinges more or less to obstruct the air exit from the duct, each flap or shutter pointing forward into the duct air stream.

470,938. *Improvements in or relating to Engine Mounts.* United Aircraft Corporation, 400, South Main Street, East Hartford, Connecticut, U.S.A. Convention date (U.S.A.), May 21st, 1935.

The proposed mounting is resilient and has a mounting ring and a number of brackets having spaced hangers and a mounting block yieldingly connected to the hangers of the bracket by resilient connections spaced apart radially of the ring.

471,926. *Improvements in Cooling Systems for Aircraft Engines.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England.

It is proposed to mount the radiator of an aircraft engine in a tunnel in the wing, the tunnel being designed so as to convert some of the kinetic energy of the air stream to pressure energy before the radiator and to reconvert after the radiator. The tunnel has an intake in the leading edge of the wing and an outlet underneath the wing, the in-stream passing through the radiator in a direction the reverse of the direction of travel of the aircraft in a downward direction. Exhaust gas may be discharged into the rear of the radiator tunnel.

473,601. *Multiple Motor Drive for Aircraft.* Menasco Manufacturing Co., 6718, McKinley Avenue, Los Angeles, California, U.S.A. Convention date (U.S.A.), March 10th, 1936.

It is proposed to couple motors together by a gear so that a single propeller may be driven by more than one motor. The gear proposed has a single gear wheel on the propeller shaft into which are geared pinions driven by the motors. Interposed between the motors and the pinions there are over-running clutches so that if one of the motors cuts out it is automatically disconnected while the drive is continued by the other motors.

472,820. *Improvements in the Cooling of Engines, Particularly for Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and de Paravicini, T. P., The Old Manor, Abbotts Ann, Andover, Hants. Dated March 26th, 1936. No. 9,064.

It is proposed to place the cooling surfaces in a duct, the inlets and exits being placed in positions where the air is, when the machine is flying, at a pressure higher than the static, circulation of the air being enforced by fans. The inlets and exits are placed where the external pressures do not vary much whatever the speed of the aeroplane. The air forced through the duct is preferably at a speed of less than one-third of the forward speed of the aircraft.

472,850. *Improvements in Propulsion Units for Aircraft.* Tennant, W. J., 111/112, Hatton Garden, London, E.C.1. Dated April 21st, 1936. No. 11,428.

The proposed propulsion means consist of one or more rotary compressors for compressing motive fluid, one or more compression chambers for heating compressed fluid, one or more gas turbines for driving the compressors which are mechanically coupled with the turbines. Means are provided for controlling the supply of fuel and for producing propulsive power and for increasing the ratio of the power input to the compressors to the power available for propulsion so as to allow of a rapid increase of the quantity of fuel supplied to the combustion chamber.

473,340. *Improvements in Cooling Means for Internal Combustion Engines.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and de Paravicini, T. P., The Old Manor, Abbotts Ann, Andover, Hants, England. Dated April 8th, 1936. No. 10,374.

It is proposed to cool aircraft engines housed in a cowling and driving a tractor airscrew by collecting air from openings in the leading edge of the wing, conducting it by ducts to the engine, and discharging it through an annular slot in the front of the cowling, so that the cooling air circulates in the reverse direction to the normal. Fan circulation is used, and it is claimed that the system can be used for either air or liquid-cooled engines.

473,341. *Improvements in Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and de Paravicini, T. P., The Old Manor, Abbotts Ann, Andover, Hants, England. Dated April 8th, 1936. No. 10,381.

It is proposed to cool aircraft engines by placing the radiators inside the leading edge of the wing and admitting air to them from slots in the leading edge. The air flows through the radiators in a direction approximately parallel to the wing spars, its pressure is increased by a fan and it is discharged by a slot in the wing trailing edge. Engine waste heat may be discharged into the air stream after the latter has passed the radiator. The pressure of the air is converted into kinetic energy before discharge.

472,334. *Improvements in Cooling of Air-Cooled Internal Combustion Engines for Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and de Paravicini, T. P., The Old Manor, Abbotts Ann, Andover, Hants, England. Dated April 8th, 1936. No. 10,372.

This scheme applies to engines having banks of cylinders in line and it is proposed to collect air from openings in the leading edge of the wing to lead it over the cylinders and to discharge it into the airstream flowing past the cowling, the discharge duct being shaped to convert pressure energy into kinetic and the exhaust gas being discharged into the airstream before the latter is discharged.

472,555. *Improvements in Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England, and de Paravicini, T. P., The Old Manor, Abbotts Ann, Hants, England. Dated April 8th, 1936. No. 10,373.

It is proposed to place an aero engine radiator in a position to the rear of the aircraft so as to help to balance the weight of the engine in the nose of the fuselage. The duct behind the radiator lies substantially within the profile of the fuselage and the airstream is discharged in the extreme rear of the fuselage.

475,250. *Flap Device for Cowlings of Air-Cooled Aviation and Other Engines.* Potez, H. C. A., Meaulte (Somme), France. Convention date (France), May 27th, 1936.

The movable flaps are hinged to the rear edge of the engine cowling upon the whole or a part of this edge. Stops are provided on which the flaps rest when in the position of minimum airflow, springs are provided for returning the flaps against the stops, and there is a control device for opening the flaps. The flaps may be pivoted on the trailing edge of the cowling and the control device may comprise two arc-shaped members connected with a mechanism which permits of displacing them in opposite directions so as to spread them out.

475,525. *Improvements in or connected with Cowling Flaps for Aircraft Engines.* Dodson, E., 66, Lewin Road, Streatham, London, S.W.16. Dated May 22nd, 1936. No. 14,512.

The flaps are arranged at the trailing edge of the cowling, each flap being pivoted on or near its leading edge, being capable of being operated so that all the flaps, when moved simultaneously, form a circle larger in diameter than the cowling. The leading edge of each flap is curved and opposite to each flap. The trailing edge of the cowling is also curved so that when the flap is operated the leading edge fits against the cowling so as to make a good joint. The flaps may be controlled by hand, by a thermostat, and by fluid pressure through a piston or diaphragm.

474,872. *Improvements in or relating to Power Plant comprising a Plurality of Internal Combustion Engines for Motor Vehicles, More Particularly Aircraft.* Dornier-Metallbauten, G.m.b.H., Friedrichshafen, Lake Constance, Germany. Convention date (Germany), March 21st, 1936.

It is proposed to use a number of engines which can be coupled to a hollow shaft through which passes a power transmission shaft common to all the engines, arrangements being made so that each engine can be coupled or uncoupled to this shaft. Friction clutches may be used.

FIRE PREVENTION.

471,639. *Improvements in and relating to Aircraft.* "Yacco," S. A. F., 42, Avenue de la Grande Armée, Paris, France. Convention date (Belgium), Oct. 8th, 1935.

This is a device for extinguishing carburettor fires, especially with radial engines, the cylinder heads of which project through a hood characterised by the feature that the carburettor and the outlet nozzles of the fire extinguishing means are arranged in the interior of the hood, which is provided at the front with closable openings. The space surrounded by the hood opens at the rear.

HELICOPTERS.

474,005. *Improvements in and relating to Aircraft.* Hinkson, H. S., and Lovell, G. H., both c/o Miss I. Cook, General Post Office, Georgetown, Demarara, British Guiana, South America. Dated Sept. 1st, 1936. No. 23,951.

The aircraft proposed is of the helicopter type and is fitted with a parachute which is closed on the ascent and opened on the descent. Ascending and descending propellers are provided above and below the body and propellers are also provided for forward motion. It is claimed that the machine is simple, reliable, easily handled and inexpensive.

ICE FORMATION.

473,883. *Means for Preventing the Formation of Ice on Exposed Surfaces.* The Harshaw Chemical Co., Elyria Lorrain, Ohio, U.S.A. Convention date (U.S.A.), Feb. 20th, 1935.

It is proposed to distribute an ice-destroying liquid over the surface by allowing it to exude in a capillary flow on to the front of the surface so that it is spread over the surface in a film. The liquid is conducted by a tube which has a fine slot opening and containing a fibrous wicking. Glycerine is preferred for the liquid.

INSTRUMENTS.

469,032. *Improvements relating to Position Indicators for Aircraft Parts, such as Undercarriages and Flaps.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Jan. 16th, 1936. No. 1,471.

For the purpose of indicators for retractable undercarriages, flaps, tail wheels, or the like, it is proposed to use an instrument having simulation parts capable of assuming positions visually corresponding to the real part. These are adapted to alter their appearance in accordance with movements of the corresponding real parts. Hence, the instrument comprises a pictorial representation of parts moving with the real parts by positive inter-connection so as to correspond therewith.

475,375. *Improvements in or relating to the Mounting of Gyroscopic Instruments in Aircraft.* Askania-Werke, Aktiengesellschaft Vormals Centralwerkstatt Dessau und Carl Bamberg-Friedman Kaiserallee 87/88, Berlin-Friedenau, Germany. Convention date (Germany), July 19th, 1935.

It is proposed to mount the gyroscopic instruments separately from the indicating means in any convenient part of the aircraft, connection being made by remote control mechanism. These instruments may be mounted together in a common carrier so that they can be easily removed from the aircraft.

474,602. *Improvements in or relating to Electrical Warning and Indicating Devices.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1; Brown, F. V., of the Company's address; Gambrell Bros. and Co., Ltd., and Onwood, A., both of Merton Road, Southfields, London, S.W.18. Dated April 3rd, 1936. No. 9,939.

It is proposed to use an alarm to indicate to the pilot the position of the wheels for landing, the alarm being controlled by a capsule or its equivalent which is sensitive to the air speed of the aircraft. There is an electric switch controlled by the chassis, a switch automatically controlled by the air speed giving a warning if the speed falls below a predetermined value while the chassis is partially or wholly retracted. The devices proposed may be put out of action by a switch controlled by the pilot.

475,656. *Indicating Instruments for Aircraft.* Pioneer Instrument Co., Inc., 754, Lexington Avenue, Brooklyn, New York, U.S.A. Convention date (U.S.A.), May 25th, 1935.

In order to provide an indicating means for aircraft fitted with a retractable chassis there is an air speed indicator with an air speed scale and means co-operating with this scale and connected with the chassis for fixing the pilot's attention to one portion of the scale when the chassis is extended and to another portion when the chassis is retracted. In order to do this the upper range of the scale is made less visible when the chassis is extended and the lower range of the scale less visible when the chassis is retracted. There is also an auxiliary indicator.

JET PROPULSION.

471,368. *Improvements relating to the Propulsion of Aircraft.* Whittle, F., Blackamoors, Harston Road, Trumpington, Cambridgeshire. Dated March 4th, 1936. No. 6,505.

This is an apparatus for jet propulsion. There is an air compressor which divides the output from the first compressor into a first stream which is passed out through a propulsion nozzle and a second stream, an internal combustion engine supplied by the second stream and a gas turbine supplied by the exhaust gas from the engine which drives the air compressor. The exhaust gas may

contribute to the thrust by fluid reaction. The engine may be a compressor-burner-gas turbine combustion.

KITES.

471,599. *Improvements in Kites.* Low, A. M., 1, Woodstock Road, Chiswick, London, W.4. Dated March 14th, 1936. No. 7,704.

There is described a means whereby the effective point of attachment of the cord may be varied. There are two attachments each of which can hold the cord and at least one which releases its hold when the cord is jerked. Two points of attachment are proposed between which the cord is wound, so that successive jerks release successive half turns and at each release altering the point of attachment.

MISCELLANEOUS.

468,777. *Apparatus for Landing of Land and Sea Aircraft.* Weichardt, R., Burgermeister-Smidtstrasse 59, Bremen, Germany. Convention date (Germany), April 27th, 1935. Specification not accepted.

It is proposed to provide a landing deck which can be towed by a small ship. The deck is to be floating and also hydrodynamically supported. It is to be made of material lighter than water or is to be a hollow body of any desired material.

469,049. *Hydraulic Circuits and Controls Therefor.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, Wright, J., and Trevaskis, H., of the Company's Works at Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated Feb. 19th, 1936. No. 5,013.

This specification describes methods for the remote control of machine and camera guns by hydraulic means. A valve is provided containing a displaceable valve body and by a static column of liquid against one end of which column the said body is maintained in spring loaded contact and in an inoperative position from which the said body is displaceable to an operative position against the spring by pressure exerted upon the other end of the said column by a hand-operated plunger positioned in a remote control.

469,050. *Hydraulic Circuits and Operating Devices Therefor.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, Wright, J. and Trevaskis, H., of the Company's Works, Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated Feb. 19th, 1936. No. 5,014.

This specification concerns hydraulic means for operating guns or camera guns on aircraft, and is concerned with a hydraulic circuit and valve control permitting the operation of such guns from the chief flying control during flight. There is a hydraulic circuit, part of which passes through a valve on the handle of the control which valve is normally closed by a spring. The valve has a pressure inlet, outlet and return ports selectively opened and closed by a plunger.

469,054. *Pneumatic Control Apparatus for Mechanisms such as Machine Guns and Camera Guns on Aircraft.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, Wright, J., and Trevaskis, H., of the Company's Works, Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated March 12th, 1936. No. 7,452.

This specification is concerned with pneumatic control apparatus for trigger actuation on aircraft for the control of machine and camera guns. The flying control for aircraft has a handle on which is placed the gun control which consists of spring loaded inlet and exhaust valves and an operating member displaceable along an axis passing through opposite sides of the part.

470,200. *Electrical Means for Indicating Relative Movements of Parts of Aircraft.* S. Smith and Sons (Motor Accessories), Ltd., Cricklewood Works, Edgware Road, Cricklewood, London, N.W.2, and Russell, V. J. S., of the Company's address. Dated May 4th, 1936. No. 12,548.

The object of this arrangement is to give information to the pilot of relative movements between different parts of the machine, such as folding chassis, and to inform him whether locking apparatus has operated, etc. It consists of an electrical rheostat operated by such relative movements, an electro-magnetic indicator, and further means responsive to the action of the locking gear.

473,395. *Improvements in and relating to Kites.* Van Ittersum, W. H. A. G., Soestdijker, Straatweg, 221, Zuid Bilthoven, The Netherlands. Convention date (France), Jan. 27th, 1936.

The kite proposed has two horizontal rotors and the lift is produced by the Magnus effect. Each rotor consists of two half cylindrical shells radially shifted relative to each other so that they are self-rotating in a wind. The rotors may, alternatively, be driven by an electric motor supplied with current from the ground.

474,862. *Safety Device for Aircraft.* Voiciechauskis, B., II Apyl Mokesciu Inspekeija. Siaulioi, Lithuania. Dated Nov. 16th, 1936. No. 31,238.

In view of the difficulty of getting an occupant out of an aeroplane in an emergency, it is proposed to provide a rail along which the occupant and his seat moves upwards or downwards and he is pushed out through an opening in the fuselage. In an aeroplane flying over the sea it is proposed to provide that the occupant becomes enclosed in a safety cabin boat. In cases where there are many occupants an emergency room is provided where they are expected to go in cases of emergency. They are then brought to the boat.

NAVIGATION.

474,821. *Improvements in Signalling for Aerial Navigation.* Braunstein, R., 6, Avenue Malakoff, Paris, France. Convention date (France), Feb. 4th, 1935.

It is proposed to fly captive balloons or kites above the fog and over the point to be signalled, and to provide them with means for sonorous signals in day time and luminous signals at night. The cable may also have signals and the balloon lights may be sodium lamps. The signals may be codified for giving the height of the balloon. The balloon may be made to descend so that the aircraft can follow it down to earth. On reaching the ground the balloon may be housed in a subterranean chamber which can be covered.

ORNITHOPTERS.

470,537. *Improvements in Oscillating Wing Aircraft.* Budig, F., 37, Quais des Grandes, Augustins, Paris VI, France. Convention date (Germany), Aug. 24th, 1935.

It is proposed that a pair of supporting and propelling wing portions are reciprocated about an axis substantially parallel to their chord to be partially telescoped within a central fixed hollow wing portion. The curvature of these wing portions may be such that the polar co-ordinates of points taken successively beyond the telescopic wing portion from tip to adjacent its root relatively to an axis of oscillation of the wind are of gradually decreasing magnitude.

PARACHUTES.

469,207. *Improvements in Parachutes.* Capel, L. J. M., 22, Rue de Musee, Marseilles, France. Convention date (France), May 14th, 1935.

It is proposed to provide means whereby a parachute can be quickly opened by means of a system of inflatable chambers secured to the canopy and made up of a chamber adopted to extend round the canopy adjacent to its periphery and a number of radially arranged chambers connected to the periphery chamber, and means for connecting the periphery chamber to a source of compressed gas adapted to be carried by the parachutist.

470,228. *Improvement to Parachute Packs.* Quilter, J. R. C., and Gregory, S., Stadium Works, Woking, Surrey. Dated Jan. 2nd, 1937. No. 108.

It is stated that it has been usual to fold the shroud lines in zigzag manner, back and forth across the pack cover, each hank thus formed being passed over a loop of webbing designed to retain the lines in place. It is proposed, instead of this arrangement, to employ webbing or loops of sufficient number and size to accommodate the folded shroud lines, one or more of the loops being adapted to vary in size at the expense of another loop in order to allow the lines an easy exit.

475,241. *Improvements in the Suspension of Parachutes.* Aerostatica Avoria, Società in Accomandita Semplice, 22, Via Pellegrino Matteucci, Rome, Italy. Convention date (Italy), March 6th, 1936.

The proposed parachute has a variable area apex vent and rigging lines reaching the elastic members that constrict said apex vent, characterised in that the connection of the rigging lines is such that the non-tensioned elastic members assume a flat position concentrically one with respect to the other and the strength of the attachment of the rigging lines to said elastic members is maintained even when one of them should break. The parts subjected to great stress are stitched herring-bone fashion.

475,245. *Improvements in Parachute Equipment, Notably in Safety Arrangements of Release Grips.* "L'Aviorex" Dreyfus Freres, 50, Rue Henri-Barbusse, Clichy (Seine), France.

This specification is concerned principally with devices in which the parachute is released by means of a Bowden control operated by a hand grip or lever and it is proposed to use a device intended to prevent involuntary release of the parachute. The grip or lever is pivotable about an axis so that the locking means are arranged so that unlocking force must be directed toward that edge of the grip on which the hand of the parachutist engages in order to move the grip pivotably.

PILOTS AND PILOTING.

476,816. *Improvements in or relating to Apparatus for Training Aircraft Pilots.* Link, E. A., 10, Avon Road, Binghampton, New York, U.S.A. Dated June 19th, 1936. No. 17,069.

After describing the usual methods for informing an aircraft pilot of his position in the air, the specification describes a method of training which consists of employing a dummy aircraft which has apparatus for transmitting to the pupil signals stimulating radio direction signals. Means are provided for automatically generating alternative signals and for transmitting them to the pupil. There is also a trainer capable of directional control within which the pilot may be enclosed so that his vision is confined to his instruments, and provided with earphones through which signals can be heard, and it may also have a visual indicating device or devices.

ROTORCRAFT.

470,757. *Improvements in or relating to Rotary Wing Aircraft.* Hutchison, H. H., and Gibson, J. J., 69, Welbeck Avenue, Portswood, Southampton. Dated Feb. 17th, 1936. No. 4,724.

This specification refers to the arrangement of a rotor hub adapted to be tilted by a lever operated by the pilot. The rotor hub is displaceable along a guide member connected with and fixed transversely with reference to the fuselage so that the displacements of the member along the guide are executed about the centre of lift of the rotor.

474,611. *Improvements in Blades for Aircraft Sustaining Rotors.* De la Cierva, J., Bush House, Aldwych, London, W.C.2. Dated May 1st, 1936. No. 12,359.

It is stated that normal methods of blade construction do not allow of the mass centre being situated sufficiently far forward. It is also desirable to minimise the bending forces in the blade and not to alter the natural frequency of the blade. It is therefore proposed to locate any additional mass either at the extreme root or near the node of the gravest mode of flexural oscillation. In certain cases it is desirable to place the weight somewhat outboard of the nodal point.

476,597. *Improvements in or relating to Rotary Wing Systems for Aircraft.* Nagler, B., Rennweg 59, Vienna III, Austria. Convention date (Austria), Feb. 8th, 1936.

It is proposed to construct blades for rotary wings by using a number of drawn tubular sections arranged lengthwise of the blades, each section having a uniform profile, the members are secured together to form the blade profile and structure.

476,598. *Flying Machine.* Nagler, B., Rennweg 59, Vienna III, Austria. Convention date (Austria), Feb. 8th, 1936.

This specification relates to aircraft having an airscrew and a rotating wing, both of which are power driven until the necessary height has been reached. The proportion of power transmitted to the airscrew and the rotary wing can be varied, the rotor can be inclined and there are two deflecting surfaces extending in the direction of the slipstream, one being fixed and adapted to counteract any tendency of the machine to overturn about its longitudinal axis owing to engine torque, the other is adjustable and can create a reaction about the rotor axis.

471,820. *Method and Apparatus for the Vertical Steering of Aircraft.* Deutsche Versuchsanstalt fur Luftfahrt E. V., Rudover Chaussee, Berlin-Adlershof, Germany. Convention date (Germany), March 12th, 1935.

It is proposed to effect the longitudinal control of rotary wing aircraft by tilting the rotating wings about an axis transverse to the pitching plane of the aircraft and simultaneously actuating an elevator in the same direction giving opposite control moments.

469,554. *Landing and Launching Device for Aircraft.* Brie, R. A. C., 26, Orford Gardens, Strawberry Hill, Twickenham, Middlesex. Dated Jan. 23rd, 1936. No. 2,203.

This proposal is primarily intended for use with rotating wing aircraft landing on ships. It consists of an apparatus incorporated in the ship structure carrying a small supporting platform capable of being swung inboard or outboard above the deck level and of being trained to suit the relative wind. The platform may be supported on a vertical pillar being overhung by means of a bracket, the bracket being rotatable on the pillar.

471,510. *Improvements in and relating to Aircraft having Rotative Sustaining Means.* Cameron, P., 7, Lancaster Crescent, Kelvinside, Glasgow. Dated Jan. 1st, 1936. No. 25.

This specification refers to a hub for the rotor of a rotary wing aircraft which is arranged to enable the head to tilt universally. There is a driving member in fixed bearings, a driven member capable of a limited universal movement and also there are arrangements for manual control of the blade angle. The blades may also move radially. The head has hinge members for the blades, bearings for the hinges and means for turning the bearings so as to alter the angle of incidence.

471,509. *Improvements in and relating to Aircraft having Rotative Sustaining Means.* Cameron, P., 7, Lancaster Crescent, Kelvinside, Glasgow. Dated 1st Jan., 1936. No. 24.

This specification relates to rotor blades which can be extended and retracted. As the blades flex upwards in varying degrees according to the state or position of the aircraft there is difficulty in retracting and extending. The means proposed act only on the blade at the moment when the flexure is small and each blade has resilient means which, when the flexure of the blade offers too great resistance to extension, takes up the movement of the blade operating means and transfers same to the blade when its flexure is less.

470,982. *Improvements in and relating to Means for Landing and Launching Gear.* Brie, R. A., 26, Orford Gardens, Strawberry Hill, Twickenham, Middlesex. Dated Feb. 28th, 1936. No. 6,036.

This specification relates to rotary wing aircraft and provides means for enabling them to be operated from stations adjoining a sheet of water. The small platform required is located near the shore but over the water. The platform may be movable to permit of training.

472,306. *Improvements in and relating to Aircraft with Auto-Rotative Wings.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), April 2nd, 1935.

This specification describes a rotary wing aircraft in which the engine is situated below the centre of gravity, the airscrew or airscrews in front and the occupants between the engine and airscrew. The engine is connected with the airscrew by a driving shaft. The airscrew axis passes approximately through the centre of gravity and there is a bevel gear between the driving shaft and the propeller shaft. The pilot's seat is situated well in front so that his view is excellent. Fuel tanks are situated on the centre of gravity, and the engine is enclosed in a compartment whose forward wall at least is fireproofed.

472,547. *Improvements in and relating to Aircraft with Autorotative Wings.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2, England. Convention date (U.S.A.), April 2nd, 1935.

This is a rotary wing aircraft in which the engine can be connected to the airscrew and also to a wheel of the undercarriage through reduction gearing. Arrangements are provided to prevent simultaneous driving of both the wheel and the airscrew. The driveable undercarriage wheel may be steered. The rotor may be driven by the engine. The engine may be cooled by an engine driven blower and there is a clutch so that the blower is automatically connected when the airscrew is disconnected.

475,230. *Improvements in and relating to Aircraft with Rotative Wings.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), Jan. 13th, 1936.

This arrangement is applicable to helicopters and also to rotary wing aircraft where there is a transmission of power from the engine to the rotary wing for the purpose of starting the latter and which are fitted with a land chassis. It is proposed to drive one or more of the chassis wheels for the purpose of enabling the machine to travel on a road under its own power. The road wheels are driven from the same gear box controlling the motor and means are provided for preventing the wheels and rotor being driven simultaneously, and there is a single friction clutch in the transmission systems, both of the rotor and the wheels.

474,681. *Improvements in and relating to Aircraft with Autorotative Sustaining Rotors.* Juan de la Cierva, Bush House, Aldwych, London, W.C.2. Dated Nov. 4th, 1936. No. 12,619.

In the case of rotating wings it is stated that an improvement of efficiency is obtained if displacement of the blade in the plane of rotation in a leading direction is associated with a decrease of angle. This specification describes a method of combining this action with an automatic or semi-automatic operation of the starting method.

476,596. *Improvements in or relating to Rotary Wing Systems for Aircraft.* Nayler, B., Rennweg 59, Vienna III. Austria. Convention date (Austria), May 16th, 1936.

This specification refers to rotor blades which can flap about axes intersecting one another at the axis of rotation of the wing system, and of turning about axes extending longitudinally of the blades. The blades are turned by levers mounted on a carrier, pivotally mounted on the carden so as to be capable of turning with it about the pivotal mounting of the latter on the driving shaft. The movement of the steering rod is transmitted to the blades through the universal joint, the centre of which is located at the point of intersection of the flapping axes and the axes of rotation of the wing system.

UNDERCARRIAGES.

475,019. *Improvements in and relating to Undercarriages for Aircraft.* Elektronmetall G.M.B.H., Pragstrasse 25, Stuttgart-Bad Constatl, Germany. Convention date (Germany), June 15th, 1936.

This arrangement is described in connection with a wheel support of the fork type and is concerned with the method of attaching the wheel axle. The ends of the axle are reduced in diameter and the surfaces of contact consist of radial teeth and are drawn tightly together by means of a screw bolt.

474,460. *Improvements in or relating to the Control of Aircraft Brakes.* Bendix, Ltd., King's Road, Tyseley, Birmingham 11, and Roberts, G. P., of the Company's address. Dated May 15th, 1936. No. 13,738.

This is an arrangement for operating brakes for parking differentially for steering, or for retarding ground movement. Two levers are provided which operate valves and which can be moved together by a hand control and which can be moved differentially by cams on a shaft which is controlled from the rudder bar.

473,768. *Improvements relating to Aircraft Undercarriages.* Dowty, G. Arle Court, Cheltenham, Gloucestershire. Dated May 7th, 1936. No. 12,955.

It is proposed to provide a unitary shock absorbing system for undercarriages capable of ready adjustment so as to cope with changing conditions. A wheel mounting is formed as a unit comprising a frame pivotally mounted so as to be deformable under landing load against a shock absorber. There is provision for the variation at choice of the position of the axes of pivots, ratio between vertical wheel travel. The resistance of the shock absorber can be readily varied. A wheel containing an internal shock absorber may be used.

470,581. *Fluid Pressure Braking and Steering Apparatus.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, Wright J., and Trevaskis, H., of the Company's Works at Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated Feb. 19th, No. 5,012, and Nov. 10th, 1936, No. 30,592.

This specification concerns fluid pressure braking and steering apparatus and the apparatus proposed has a pair of hydraulic valves, each with an outlet port and also with an inlet and return port, which latter ports are spaced apart along the axis of each valve casing and are closed in the inoperative position by the wall of a hollow piston, one end of which piston is open and remains coaxial with the outlet port, the said wall being formed with posts displaceable in one direction to register with the inlet port and in the other direction to register with the return port.

469,407. *Improvements in and relating to Brakes for Aircraft Wheels.* The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., Thames House, Millbank, London, S.W.1, and Tarris, F. J., of the Company's Works at Silvertown, London, E.16. Dated Jan. 23rd, 1936. No. 2,225.

This specification is concerned with fluid controlled or vacuum controlled brakes and is arranged for differential braking so that the aircraft may be steered on the ground. It is proposed to use a control mechanism having a pair of auxiliary control devices each comprising means, such as a valve or plunger, to release partially or wholly the braking pressure in that brake set to which the device is connected, a movable element in alignment with and controlling the said brake releasing means and a plunger which is separate from and additional to the brake releasing means and which is acted upon directly by the actuating fluid from the main control device wherein the movable element and the plunger are mounted for simultaneous movement as an integral unit.

471,488. *Improved Brake Operating Means for Aircraft.* Fitt, G., and Barber, P. M., both of Tankerton Garage, Tankerton, Kent. Dated March 3rd, 1936. No. 6,440.

It is proposed to use an apparatus by means of which aircraft brakes cannot be applied unless the tail member is on the ground. There is a source of fluid under pressure from which branch two channels, on leading to a safety valve, normally open to the atmosphere, but closed by movement of the tail member, the other leading to a brake valve controlled by the throttle lever so as to be open over the full or nearly full working range of the lever, but closed during the last movement of the lever towards the closed position.

470,928. *Improvements in and relating to Undercarriages for Aircraft.* Brie, R. A. C., 26, Orford Gardens, Strawberry Hill, Twickenham, Middlesex. Dated Feb. 25th, 1936. No. 5,631.

It is stated that the requirements for undercarriages for rotary winged aircraft are different from those for aeroplanes, an extra long shock absorbing travel

being advisable for landing, while for getting off no springing arrangement is necessary. Under certain circumstances, however, on getting off some shock absorbing arrangement may be required. It is proposed to use, therefore, an undercarriage which includes a locking device operated by the pilot for positively locking together relatively moving members of the undercarriage so as to prevent it from developing its full extensibility.

471,944. *Improvements in or relating to Landing Gear for Aircraft.* Delanne, M. H., 17, Rue Servandoni, Paris, France. Convention date (France), June 29th, 1935.

In order to reduce the weight and resistance of aircraft, it is proposed to use a chassis consisting of a single wheel supported in a stirrup connected to the fuselage in such a manner as to be retractable. The proposed tail support consists of two wheels spaced apart laterally, they may be mounted on the extremities of the tail plane.

470,967. *Improvements in or relating to Vehicle Brakes.* The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., Thames House, Millbank, London, S.W.1, and Tarris, F., of the Company's Works, Silvertown, London, E.16. Dated Jan. 23rd, 1936. No. 2,226.

In a brake mechanism there is a multi-way valve having connections for pipes and passages leading from the connections to openings in the upper surface of the base, a flexible diaphragm to form one wall of a chamber affording communication between the openings and means applied to that side of the diaphragm remote from the openings selectively to effect a lateral shift of the diaphragm over small areas adjacent to the openings so as to apply the diaphragm directly thereto and close them against passage of pressure fluid.

473,387. *Improvements in or relating to Retractable Alighting Gear for Aeroplanes.* Ehrhardt, P. G., 15, Grillparzenstrasse, Frankfort, Main, Germany. Convention dates (Germany), Nov. 14th, 1935, and Nov. 10th, 1936.

In this folding chassis it is proposed that the gaseous medium for shock absorbing is separated from the liquid medium which transmits shocks and which operates the retracting gear by a flexible partition. The gaseous medium is under pressure in the retracted position as well as in the unfolded position so long as they do not carry the weight of the machine. Means are provided for indicating the fluid pressures on the pistons belonging to the struts and eventually on the tail skid, and a sole measuring instrument is provided so that the pilot can control on the ground the weight and distribution of the fuel and useful load.

473,425. *Improvements relating to Locking and/or Indicating Means for Retractable Aircraft Undercarriages.* Dowty, G. H., Arle Court, Cheltenham, Gloucester. Dated March 12th, 1936. No. 7,507.

Means are proposed to prevent accidental retraction of undercarriages while the machine is standing on the ground. The means may operate directly on the undercarriage itself, or may cut out the retraction gear. Yielding of the shock-absorbing gear may operate a switch cutting out indicating lights.

473,202. *Improvements in and relating to Retractable Undercarriages for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucester. Dated April 8th, 1936, No. 10,380; Dec. 9th, 1936, No. 33,845; Jan. 4th, 1937, No. 236; and Jan. 12th, 1937, No. 951.

The arrangement proposed relates to the locking of folding chassis operated by hydraulic jacks. The locking means for holding the gear in either of its extreme positions may be operated by the supply to the jack of fluid in excess of

that required to raise and lower the chassis. Where the jack is double acting locking means are provided except when such means are moved by lost motion of the jack. The locking member may be resiliently urged to lock and pressure operated to unlock. The lock may be operated by a minor piston moved by fluid pressure on its way to or from the jack cylinder or it may be operated directly by pressure in a cylinder through which pressure is transmitted after completion of stroke to the jack.

475,222. *Improvement in Landing Gear for Aircraft.* Saulnier, R., 5, Rue de Monceau, Paris, France. Convention date (France), Nov. 23rd, 1935.

This specification claims improvements on the chassis described in specification 456,632. In order to ensure that the gear shall unfold even if there is a failure to the oil supply to the jack, it is proposed to introduce a safety apparatus intended to produce the requisite movement. A further modification is introduced by a piece of apparatus intended to lock the jack in the unfolded position.

475,504. *Improvements in or relating to Retractable Undercarriages for Aircraft.* The Supermarine Aviation Works (Vickers), Ltd., Mitchell, R. J., and Black, A., all of the Company's Works, Woolston, Southampton, Hants. Dated May 19th, 1936. No. 14,165.

This is a pneumatically operated retracting chassis in which the source of gas under pressure is supplied from a cylinder. There is an emergency cylinder containing liquid for generating gas under pressure for use in case the main supply fails. There is also, in addition to the control valve, a shuttle valve in the pipe between the cylinder and the gear. This shuttle valve controls the change over between the cylinder and the emergency cylinder.

473,756. *Improvements relating to Aircraft Undercarriages with Resilient Wheel Units.* Dowty, G. H., Arle Court, Cheltenham. Dated March 16th, 1936. No. 7,908.

The wheel is fitted with an internal shock absorber, one portion of which is fixed to the non-rotating hub and the other is guided for reciprocating movement in said hub. Each part is fixed to the radial side of a frame which is articulated for deformation and the sides of which are adapted to be attached pivotally at axes which are spaced apart to an otherwise complete undercarriage. The deformation of the frame while landing against the restraint of the shock absorber results in a substantially greater wheel movement.

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

SEVENTY-THIRD ANNUAL REPORT OF THE COUNCIL.

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The Membership of the Society for 1937 shows a net increase, after allowing for members suspended, of 198 over 1936. The figures in brackets give the membership in 1936. The membership of the Society is now, for the first time in its history, close to 2,000 and there is every sign that it will continue to increase at its present rate for some years to come.

In 1937 a new grade of Graduate was formed for those Students who held a degree or its equivalent, and 25 students have joined the new grade.

	No. of Members.		Honorary & Life Members.		Suspended.		Total.	
Fellows	156	(144)	20	(23)	2	(1)	178	(168)
Members	55	(54)	1	(1)	1	(1)	57	(56)
Associate Fellows	612	(526)	5	(6)	7	(8)	624	(540)
Associate Members... ...	156	(134)	—	(—)	6	(11)	162	(145)
Associates	236	(220)	3	(3)	15	(13)	254	(236)
Graduates	25	(—)	—	(—)	—	(—)	25	(—)
Companions	116	(107)	10	(8)	8	(7)	134	(122)
Founder Members	24	(24)	1	(1)	1	(1)	26	(26)
Students	468	(442)	—	(—)	38	(33)	506	(475)
Temporary Hon. Members	—	(—)	30	(26)	—	(—)	30	(26)
	1848	(1651)	70	(68)	78	(75)	1996	(1794)
Less Joint Members ...	26	(25)					26	(25)
	1822	(1626)	70	(68)	78	(75)	1970	(1769)

DONATIONS.

The Council have to thank the Air Ministry for the thirteenth year in succession for their generous grant of £250 to the Funds of the Society, and the Society of British Aircraft Constructors, also for the thirteenth year in succession, for a similar donation.

The President and Council have had under constant review the necessity of increasing the reserve funds of the Society, apart from the existing Endowment Fund, so that the Society may have the opportunity of expanding its activities in various ways, particularly for encouraging the presentation of papers, technical education and the furthering generally of the scientific and engineering side of aviation.

In the last year's Council Report the Council recorded their thanks to Mr. C. R. Fairey, M.B.E., F.R.Ae.S., and Mr. Handley Page, C.B.E., F.R.Ae.S., for their generous gifts of £2,625 under seven year deeds.

This year the President and Council place on record their appreciation of the following generous gifts under seven year deeds:—

Mr. Oswald Short	...	£10,000
Mr. Handley Page	...	£7,378 (making £10,000 in all)
Lord Kenilworth	...	£5,000
Mr. R. Blackburn	...	£5,000
Mr. W. C. Devereux	...	£1,500

a total sum of £28,878.

These donations will enable the Council to plan ahead and to carry out many of the objects which they have in mind for increasing the influence of the Society and to advance the cause of aeronautical science and engineering.

ENDOWMENT FUND.

The table below gives the progress of the Endowment Fund:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	0
December, 1932	2,196	2	0
December, 1933	9,716	19	5
December, 1934	10,131	14	11
December, 1935	10,895	10	7
December, 1936	11,138	16	7
December, 1937	11,474	3	7

The Endowment Fund Trust Deed specifically ensures that every contribution to the Fund will be devoted to the provision of the Society's own building. The Council have made extensive inquiries during the past year and inspected a number of possible sites. The problem has proved difficult of solution owing largely to the lack of the necessary capital involved. The Endowment Fund should be at least £50,000 if the Society is to acquire and endow premises of a suitable nature. The final decision must rest upon financial considerations and every effort is being made by the Council to increase the Endowment Fund to the required sum.

LIBRARY.

Mr. J. E. Hodgson, Hon. F.R.Ae.S., has acted as Honorary Librarian for fourteen years in succession and the Council wish to place on record their appreciation of the value of his advice and help in all matters pertaining to the Library.

The Society during the year was bequeathed the aeronautical papers, books and slides belonging to the late Major B. F. S. Baden-Powell and the collection is now being classified. In it are many letters and papers of great historical interest which will add greatly to the value of the Library.

The Council particularly wish to thank those members who have helped to enrich the Society's slide and photographic collections, which are now among the most representative of such collections in the world.

The technical index which was begun some years ago has been called upon very largely during the year by members and others and its use in answering numerous questions on every aspect of aviation has saved much valuable time.

GARDEN PARTY.

The Society held its Annual Garden Party on Sunday, May 9th, 1937, at the Great West Aerodrome, near Hayes, again by kind permission of Mr. C. R. Fairey, M.B.E., F.R.Ae.S., Past-President of the Society. Despite the bad weather the attendance was greater than in any previous years, over 3,000 members and their guests attending. A full report of the Garden Party was published in the Journal for December, 1937.

WILBUR WRIGHT MEMORIAL LECTURE.

The Twenty-fifth Wilbur Wright Memorial Lecture, entitled " Turbulence," was delivered before the Society on May 27th, 1937, in the Lecture Hall of the Institution of Electrical Engineers, by Professor T. von Kármán, of Pasadena University, California. The lecture was followed by the Annual Council Dinner at the Athenæum, at which a number of distinguished guests were present. A full report of the lecture and dinner was published in the Journal for December, 1937.

RECEPTION.

On January 19th, 1938, the Vice-Presidents and Council held a Reception in the Science Museum (Aeronautical Section), South Kensington, to commemorate the 72nd Anniversary of the founding of the Society. Over 500 members and guests were present and were received by Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President, and Mrs. F. Handley Page.

During the evening there was a display of films showing the way a petrol engine works and unusual aircraft. The films were shown by the courtesy and help of the Shell Mex Company, British Movietonenews, Paramount British News and Captain Liptrot. A demonstration of television was also given by courtesy of the Gramophone Company, Limited (His Master's Voice), of Bond Street, London, W.1.

The following awards were presented during the reception by Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President :—

Simms Gold Medal.—To Dr. N. A. de Bruyne for his paper on " Plastic Materials for Aircraft Construction." The Simms Gold Medal is awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, *e.g.*, meteorology, wireless telegraphy, instruments.

Taylor Gold Medal.—Mr. George Mead, A.F.R.Ae.S., for his paper on " Power Plant Trends." The Taylor Gold Medal is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

Wakefield Gold Medal.—To Dr. G. V. Lachmann, F.R.Ae.S. The Wakefield Gold Medal is awarded annually to the designer of any invention or apparatus tending towards safety in flying, and is open to members or non-members.

Edward Busk Memorial Prize.—The Edward Busk Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes or seaplanes. This year two papers were considered of equal merit and the prize was divided between Major B. C. Carter, M.I.Mech.E., A.R.C.Sc., D.I.C., F.R.Ae.S., for his paper on " Airscrew Blade Vibration," and Mr. A. G. Pugsley, B.Sc., A.M.I.Struct.E., A.F.R.Ae.S., for his paper on " Control Surface and Wing Stability Problems."

Pilcher Memorial Prize.—The Pilcher Memorial Prize is offered annually for the best paper by a Student on heavier-than-air craft or any analogous subjects. This year two papers were considered of equal merit and a

Pilcher Memorial Prize was awarded to Mr. A. J. Hanson, B.Sc., for his paper on " Critical Speeds of Monoplanes," and Mr. C. O. Vernon for his paper on " Aircraft Performance Estimation."

R.38 Memorial Prize.—To Mr. A. A. Hall, B.A., for his paper on " The Turbulence and Skin-Friction Problems." The award is offered annually for the best paper received by the Society on some subject of a technical nature in the science of aeronautics, preference being given to papers which relate to airships.

LECTURE PROGRAMME.

A full list of lectures delivered before the Society, and the principal lectures before the Branches, were given in the Journal for December, 1937. In addition the following lectures have been delivered or arranged for during the remainder of the Session :—

Jan. 13th, 1938.—Squadron Leader R. S. Blucke, A.F.C., " The Practical Use of Radio as a Direct Aid to the Landing Approach in Low Visibility."

Jan. 27th, 1938.—Discussion on " High Wing Loading and the Three-Wheeled Undercarriage."

Feb. 3rd, 1938.—E. F. Relf, Esq., F.R.S., F.R.Ae.S., " Recent Research on the Development of the Aerodynamic Characteristics of Aircraft."

March 3rd, 1938.—Dr.-Ing. W. Pleines, " Riveting Methods in German Aeroplane Construction."

April 7th, 1938.—E. G. Richardson, Esq., B.A., D.Sc., Ph.D., " The Manipulation of the Boundary Layer."

April 21st, 1938.—Professor J. E. Younger, Ph.D., A.F.I.Ae.S., " High Altitude Flying."

April 28th, 1938.—Dr. G. E. Bairsto, M.I.E.E., F.Inst.P., " Factors Controlling the Development of Electrical Ignition on Aero Engines."

May 26th, 1938. *Wilbur Wright Memorial Lecture.* Dr. H. Gough, M.B.E., F.R.S., " Materials of Aircraft Construction."

LECTURES BEFORE THE BRANCHES.

In addition to the list of lectures delivered before the Branches, published in the December, 1937, issue of the Journal, the following lectures have been delivered or arranged for :—

Jan. 5th.—Lecture before the Southampton Branch by Mr. H. J. Pollard, A.F.R.Ae.S., on " Aircraft Production."

Jan. 5th.—Lecture before the Weybridge Branch by Professor A. J. Sutton Pippard, M.B.E., D.Sc., F.R.Ae.S., " Experimental Methods of Structural Construction."

Jan. 11th.—Lecture before the Isle of Wight Branch by Mr. R. H. Longe, " Aircraft Inspection Methods."

Jan. 13th.—Lecture before the Manchester Branch by Mr. W. C. Devereux, F.R.Ae.S., " The Future of Light Alloys in Aircraft Construction."

Jan. 13th.—Lecture before the Yeovil Branch by a Representative of Messrs. de Havilland Aircraft Company, Limited, " Aero Engine Design."

Jan. 18th.—Lecture before the Bristol Branch by Flight Lieutenant M. J. Adam, " High Altitude Flight."

Jan. 19th.—Lecture before the Weybridge Branch by a Member of the Staff of Drummond Brothers, Limited, " The Use of Multi-Tool Lathes, Gear Shapers and Broaching Machines."

Jan. 20th.—Lecture before the Portsmouth Branch by Mr. A. Hessell Tiltman, F.R.Ae.S., " Aircraft of the Future."

Jan. 20th.—Lecture before the Coventry Branch by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., " The Installation of Aero Engines."

Jan. 25th.—Lecture before the Isle of Wight Branch by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., A.F.I.Ae.S., "Bird Flight in Relation to the Aeroplane."

Feb. 2nd.—Lecture before the Weybridge Branch by Major P. L. Teed, M.Inst.M.M., "The Heat Treatment of Duralumin."

Feb. 8th.—Lecture before the Isle of Wight Branch by Mr. L. P. Coombes, D.F.C., B.Sc., A.C.G.I., A.F.R.Ae.S., "Tank Testing of Flying Boat Hulls with its Application to Full Scale."

Feb. 10th.—Lecture before the Manchester Branch by Mr. H. B. Irving, B.Sc., F.R.Ae.S., "Wing Flaps and Tapered Wings."

Feb. 10th.—Lecture before the Portsmouth Branch by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., "Cowling and Cooling of Radial Engines."

Feb. 10th.—Lecture before the Yeovil Branch by Mr. L. A. Sweny, "Radio for Aircraft Services."

Feb. 16th.—Lecture before the Weybridge Branch by Mr. D. A. Kitching, A.M.I.E.E., "The Electrical Installation at Vickers' Works."

Feb. 17th.—Lecture before the Coventry Branch by Major F. M. Green, O.B.E., M.Inst.C.E., F.R.Ae.S., "Aircraft Motive Power."

Feb. 22nd.—Lecture before the Isle of Wight Branch by Captain Norman Macmillan, M.C., A.F.C., F.R.S.A., A.F.R.Ae.S., "Flying and Handling of Seaplanes and Flying Boats."

Feb. 24th.—Lecture before the Portsmouth Branch by Major H. Hemming, A.F.C., F.R.G.S., F.R.Ae.S., "Air Survey."

Feb. 24th.—Lecture before the Yeovil Branch by Mr. W. O. Manning, F.R.Ae.S., "Flying with the Pioneers at Brooklands."

March 1st.—Lecture before the Bristol Branch by Dr. T. Swinden, "Steel Development as Related to the Aero Industry."

March 2nd.—Lecture before the Southampton Branch by Flt. Lieut. H. F. Jenkins, "De-Icing."

March 2nd.—Lecture before the Weybridge Branch by Mr. E. F. Relf, F.R.S., A.R.C.Sc., F.R.Ae.S., "Aerodynamic Research at the National Physical Laboratory."

March 8th.—Lecture before the Isle of Wight Branch by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., "Cowling and Cooling of Air-Cooled Aero Engines."

March 10th.—Lecture before the Portsmouth Branch by Sergeant Barnes, "Air Raid Precautions in Portsmouth."

March 10th.—Lecture before the Manchester Branch by Dr. R. C. Sutcliffe, "Clouds and Their Formation, Structure, and Associated Flying Conditions."

March 17th.—Lecture before the Coventry Branch by Captain J. L. Pritchard, Hon. F.R.Ae.S., A.F.I.Ae.S., "The Ruts of Aviation."

March 22nd.—Lecture before the Isle of Wight Branch by Captain P. W. Lynche-Blosse, "Air Route and Aerodrome Control."

March 24th.—Lecture before the Portsmouth Branch by Sir Alan Cobham, Hon. F.R.Ae.S., "Problems and Possibilities of refuelling in the Air."

April 5th.—Lecture before the Isle of Wight Branch by Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S., "Large Aeroplanes."

April 6th.—Lecture before the Weybridge Branch by Mr. I. J. Gerard, M.Sc., A.M.Inst.C.E., A.F.R.Ae.S., "Stressed Skin Construction."

April 6th.—Lecture before the Southampton Branch by Captain F. Entwistle, B.Sc., "Recent Developments in Meteorology."

April 12th.—Lecture before the Isle of Wight Branch by Mr. L. Leech, "Tool Design and Manufacture."

April 21st.—Lecture before the Coventry Branch by Mr. E. F. Relf, F.R.S., A.R.C.Sc., F.R.Ae.S., "The Compressed Air Wind Tunnel and its Results."

April 28th.—Lecture before the Manchester Branch by Squadron Leader G. M. Buxton, "Development of Sailplanes."

STUDENTS' SECTION.

A report of the activities of the Students' Section for the Session 1936-1937 was published in the December, 1937, Journal. The following is a list of lectures and visits to works arranged for the 1937-1938 Session:—

Meetings.

1937.

Sept. 30th.—Annual General Meeting.

Oct. 5th.—Inaugural Address by Lieut.-Col. J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P. Chairman: Captain J. L. Pritchard, Hon. F.R.Ae.S.

Oct. 26th.—"Detail Design," Mr. E. Voss. Chairman: Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.

Nov. 2nd.—"Light Alloy Castings and Stampings for Aeronautical Purposes," Mr. W. C. Devereux, F.R.Ae.S. Chairman: Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.

Nov. 5th.—Informal Supper at the Royal Aero Club.

Nov. 16th.—"The Mechanical Aspect of Wing Flutter Problems," Mr. P. B. Walker, M.A., Ph.D., A.F.R.Ae.S. Chairman: Mr. H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S.

Dec. 9th.—"Torsional Vibration in Engines," R. J. W. Cousins, Esq. (Joint Meeting with the Institution of Petroleum Technologists, Students Section, and the Institution of Automobile Engineers, Graduate Grade.)

1938.

Jan. 18th.—"Turbulence and Skin Friction," Mr. A. A. Hall, B.A. Chairman: Mr. H. B. Squire, M.A., A.F.R.Ae.S.

Feb. 1st.—"Notes on Aero Engine Research," Mr. P. H. Rayner, B.Sc., Grad.R.Ae.S.I. Chairman: Mr. D. R. Pye, C.B., F.R.S., M.A., Sc.D., F.R.Ae.S.

Feb. 15th.—Discussion on "Control Surface Design," opened by Mr. A. F. Walsh, B.Sc., Grad.R.Ae.S.I., and Mr. D. R. Sherwin. Chairman: Mr. J. C. Hardman.

March 1st.—"Transport Aviation in Canada," Mr. H. M. Gallay, B.Sc., M.I.Ae.S. (Student). Chairman: Mr. C. G. Grey.

March 22nd.—"Theory and Application of Stressed Skin Construction," Mr. H. E. J. Rochefort, Wh.Sch., A.C.G.I., D.I.C. Chairman: Mr. H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S.

March 29th.—"Large Aeroplanes," Mr. H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S. Chairman: Major C. J. Stewart, O.B.E., M.I.M.E., M.I.A.E., F.R.Ae.S.

April 26th.—"Atlantic Air Routes," Mr. L. R. E. Castlemaine. Chairman: Mr. D. L. Hollis Williams, B.Sc., F.R.Ae.S.

Visits.

1937.

Oct. 23rd.—Irving Air Chutes of Great Britain, Letchworth, Herts.

Nov. 13th.—De Havilland Aircraft Co., Ltd., Hatfield, Herts.

Dec. 11th.—High Duty Alloys, Limited, Slough, Bucks.

1938.

Jan. 22nd.—Fairey Aviation Works, Hayes, Middlesex.

Feb. 19th.—Marconi's Aircraft Establishments at Hackbridge and Croydon.

March 19th.—National Physical Laboratory.
April 9th.—Heston Airport.
May 18th.—Bristol Aeroplane Company Works, Bristol.

PUBLIC SCHOOLS LECTURES.

For the seventh year in succession lectures have been arranged before public schools and other educational establishments. The Council wish particularly to thank all those members who have given so much of their time to the delivery of one or more of the Schools Lectures, which form a most valuable form of propaganda.

In addition to the list published in the December Journal for 1937 the following have been arranged for, or delivered, making a total of 58 from October, 1937—March, 1938:—

Feb. 4th.—Lecture before the Engineering Society, University College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "The Queer Side of Flying."
Feb. 11th.—Lecture before Rutherford College, Newcastle-upon-Tyne, by Mr. J. Bell, A.R.Ae.S.I., on "A Trip into the Stratosphere."
Feb. 15th.—Lecture before the Grantham Engineering Society, Grantham, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Flying in the Stratosphere."
Feb. 16th.—Lecture before Hornsey Central Library by Mr. H. T. Winter on "Flight Yesterday, To-day and To-morrow."
Feb. 17th.—Lecture before Golders Green Library by Mr. H. T. Winter on "Flight Yesterday, To-day and To-morrow."
March 1st.—Lecture before East Ham Central Library by Mr. H. T. Winter on "A Trip into the Stratosphere."
March 10th.—Lecture before Wood Green Library by Mr. H. T. Winter on "A Trip into the Stratosphere."

BRANCHES.

During the year two new Branches were formed, one at Weybridge and one in the Isle of Wight. Both have made an excellent start not only in membership but in their programmes of lectures. There are now thirteen branches of the Society and the Council congratulate all those concerned with the progress which has been made. This is particularly due to the Chairmen, Committee and Honorary Secretaries upon whom the real success of a branch depends.

The following is a list of Branches:—

Australian Branch.

Chairman: T. D. J. Leech, B.Sc., B.E., M.I.Ae.E.
Hon. Secretary: Philip H. Vyner, A.M.I.Ae.E.
Address: Science House, Gloucester and Essex Streets, Sydney, Australia.

Bristol Branch.

President: H. J. Thomas, Esq.
Chairman: N. Rowbotham, Esq., A.F.R.Ae.S.
Hon. Secretary: H. Yendall, Esq.
Address: 20, The Crescent, Henleaze, Bristol.

Cambridge University Engineering and Aeronautical Society (affiliated to the Royal Aeronautical Society).

President: R. H. Angus, Esq., M.A.
Aeronautical Section—President: J. A. F. Jarrow, Esq.
Secretary: J. J. Holden, Esq.
Address: Clare College.

Coventry Branch.

Chairman: Air Marshal Sir John Higgins, J.P., K.C.B., D.S.O., A.F.C., F.R.Ae.S.
Hon. Secretary: S. A. Powell-Jones, Esq.
Address: Sir W. G. Armstrong-Whitworth Aircraft Limited, Coventry.

Gloucester and Cheltenham Branch.

President: T. O. M. Sopwith, Esq., C.B.E., F.R.Ae.S.
Chairman: W. G. Carter, Esq., M.B.E., F.R.Ae.S.
Hon. Secretary: F. B. Ford, Esq., A.F.R.Ae.S.
Address: St. Margaret, Brockworth, Nr. Gloucester.

Hull and Leeds Branch.

Chairman: Major F. A. Bumpus, B.Sc., F.R.Ae.S.
Hon. Secretary: G. B. Fenton, Esq., A.F.R.Ae.S.
Address: c/o Fairview, Brough, Yorks.

Isle of Wight Branch.

President: Sqdn. Ldr. C. J. W. Darwin, D.S.O.
Chairman: H. Knowler, Esq., A.M.Inst.C.E., A.F.R.Ae.S.
Hon. Secretary: B. W. Townshend, Esq., A.C.G.I., A.M.I.Mech.E., A.F.R.Ae.S.
Address: Kite Hill Lodge, Wootton, I.O.W.

Manchester Branch.

Chairman: R. Chadwick, Esq., A.F.R.Ae.S.
Hon. Secretary: J. A. E. Waterfall, Esq.
Address: 56, Manor Avenue, Ashton-on-Mersey, Cheshire.

Montreal Branch.

Address of Hon. Secretary: Engineering Institute of Canada, 2050, Mansfield Street, Montreal, Canada.

Ottawa Branch.

Hon. Secretary: M. S. Kulving, A.R.Ae.S.I.
Address: National Research Council, Aeronautical Laboratory, Ottawa, Ontario, Canada.

Portsmouth Branch.

President: A. H. Tiltman, Esq., B.Sc., F.R.Ae.S.
Chairman: L. Newall, Esq.
Hon. Secretary: H. I. Birds, Esq., B.Sc., A.F.R.Ae.S.
Address: " Elmcroft," Victoria Road North, Southsea, Hants.

Southampton Branch.

Chairman: Wing Comdr. T. R. Cave-Browne-Cave, C.B.E., M.I.Mech.E., F.R.Ae.S.
Hon. Secretary: T. Tanner, Esq., A.C.G.I., D.I.C., A.F.R.Ae.S.
Address: University College, Southampton, Hants.

Weybridge Branch.

President: R. K. Pierson, Esq., M.B.E., B.Sc., A.M.Inst.C.E., F.R.Ae.S.
Chairman: F. Holliday, Esq., B.Sc., A.R.Ae.S.I.
Hon. Secretary: M. W. Wood, Esq., A.F.R.Ae.S.
Address: c/o Vickers (Aviation), Limited, Weybridge, Surrey.

Yeovil Branch.

President: Captain P. D. Acland.
Hon. Secretary: T. H. Burleigh, Esq., A.R.Ae.S.I.
Address: Westland Aircraft, Limited, Yeovil, Somerset.

PRESIDENT.

Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S., was elected President of the Society for a second term of office at the Council Meeting held in May, 1937.

VICE-PRESIDENTS.

The following were elected Vice-Presidents of the Society at the May, 1937, meeting of Council:—

Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.
Mr. A. H. Hall, C.B., C.B.E., M.Inst.C.E., M.I.M.E., F.R.Ae.S.
Mr. F. Handley Page, C.B.E., F.R.Ae.S.
Mr. D. R. Pye, C.B., F.R.S., M.A., Sc.D., M.I.Mech.E., F.R.Ae.S.

JOURNAL.

The Journal for 1937 showed a considerable increase in contents over previous years. The cost of printing and circulating copies of the Journal to members is one of the heaviest items in the Annual Budget. Much of that cost has been offset by a steadily increasing advertisement revenue and by outside sales of the Journal, and the loss on the Journal compares extremely favourably with that of corresponding societies

The Income and Expenditure Account of Aerial Science Ltd. gives a summary of the expenditure on the Journal and sundry publications, *e.g.*, advance proofs of lectures, reprints of papers, etc. The stock of Journals, etc., has been written down to a nominal value of £1.

The income and expenditure of the Journal is as follows:—

	£	s.	d.		£	s.	d.
Printing costs ...	2,695	0	0	Sales	1,228	19	1
Postages	326	15	4	Advertisement revenue ...	1,919	10	9
Other charges (including blocks)...	453	1	8	Loss	326	7	2
	£3,474	17	0		£3,474	17	0

FINANCE.

The Income and Expenditure Accounts and Balance Sheets of Aerial Science Limited and Aeronautical Trusts Limited for 1937 are published in this issue of the Journal.

The Income and Expenditure Account of Aerial Science Limited shows a loss on the year of £47 4s. 5d., as against a surplus of income over expenditure of £1,579 1s. 10d. in 1936. The latter figure was, however, arrived at after taking credit for certain donations which have this year been placed to capital account. In addition the Journal stock has this year been written down and also the value of furniture, these items totalling £1,402 19s. 6d. There is also an increased loss on the Journal of £147 15s. 11d.

It is clear from the accounts that with its present expenditure and income the Society is in a satisfactory financial condition, but without a considerable increase in income, from capital investments or otherwise, it is not in a position to extend its activities on a much greater scale than at present.

OFFICERS OF THE SOCIETY.

The Council wish to place on record their appreciation of the work which has been carried out by the Officers of the Society.

Mr. Wingfield, Solicitor to the Society, has freely placed his legal knowledge at the disposal of the Council and its Committees and has given much helpful advice during the past year.

In 1937 Major D. H. Kennedy, O.B.E., F.R.Ae.S., completed eleven years' continuous service as Honorary Treasurer of the Society. Major Kennedy has been one of the most active members of the Finance Committee and has continually put the interests of the Society in the foreground when financial matters have come up for consideration.

For the tenth year in succession Mr. A. N. D. Smith has held the office of Honorary Accountant to the Society and has given invaluable help and advice on the Finance Committee. Mr. Smith has initiated methods of keeping and presenting the Society's accounts which have considerably simplified the work.

The Council wish particularly to thank the Chairmen and Members of Committees of Council for their work on behalf of the Society during the year under review. The Finance and Development Committees, under Major J. S. Buchanan; the Education and Examinations Committee, of which Professor G. T. R. Hill is Chairman; Medals and Awards Committee, under Professor G. T. R. Hill; and the Lectures Committee, under Mr. A. H. Hall, have relieved the Council of a very considerable amount of the actual carrying out of the Society's routine work, and every member of the Society owes these voluntary committees a great debt of gratitude for the services they so freely give to the Society. The Grading Committee, which does not have a fixed Chairman, has done most invaluable work during the year, considering every application for technical membership of the Society in detail.

The Council would also like to thank those representatives of the Society on other bodies and committees who have enabled the Council to keep in close touch with the activities of other Societies.

STAFF.

The credit of the smooth running of the Society and the successful carrying out of the policies of the Council lies finally with an efficient staff

The Society is fortunate in having a staff whose individual interest in its aims enable the work of the Society to be carried out in a most efficient way.

Under the direction of the Secretary, Captain Pritchard, Miss F. Barwood is responsible for the general work and organisation, Miss B. Voyce for the Society's accounts, Miss R. Parkes for the greater part of the clerical work, together with Miss S. Dennis, who joined the staff at the beginning of the year. Mr. R. McWilliam is responsible for the advertisements for the Journal, and is also responsible for slides and photographs used in connection with the Public Schools lectures and other educational bodies.

THE ROYAL
(Aerial

Balance Sheet,

	£ s. d.	£ s. d.
Share Capital—		
Authorised—		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
Issued—		
19 Shares of 1/- each, fully paid		0 19 0
Sundry Creditors		681 14 7
Subscriptions and Other Amounts Received in Advance		450 8 2
Staff Pensions Fund		100 0 0
Surplus—		
Capital Accumulations Account—		
Donations during year...	4875 8 5	
Income and Expenditure Account—		
Balance at 31st December, 1936 ... ... 2650 15 4		
Less—Excess of Expenditure over Income for year to date 47 4 5	2603 10 11	7478 19 4
		£8712 1 1

We report to the Members that we have examined the above Balance Sheet with the Books are of the opinion that the Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.
17th February, 1938.

Income and Expenditure Account

Dr.	£ s. d.	£ s. d.
To Establishment Expenses—		
Rent, Heating, Lighting and Insurance		608 19 1
,, Office and Staff Expenses—		
Salaries	1494 3 11	
Printing and Stationery	529 19 3	
Postages	259 8 5	
Other Charges	615 17 3	2899 8 10
,, Expenditure on Journal and Sundry Publications—		
Printing Costs	2695 0 0	
Postages	326 15 4	
Opening Stock written down to £1	249 0 0	
Other Charges	453 1 8	
	3723 17 0	
Less—Sales 1228 19 1		
Advertisement Revenue 1919 10 9	3148 9 10	575 7 2
,, Meetings		205 18 8
,, Library Expenses		69 4 11
,, Slides and Photographs		12 5 5
,, Prizes and Donations		46 4 6
,, Dinners and Receptions—Expenses	204 0 5	
Less Receipts	107 0 0	97 0 5
,, Legal and Professional Charges		80 8 6
,, Staff Pensions Fund...		100 0 0
,, Amount written off Furniture, Printed Books, etc.		403 19 6
		£5098 17 0

The Royal Aeronautical Society Endowment Fund

1937		£ s. d.
Jan. 1.	Fund at commencement of year	11138 16 7
Dec. 31.	Investment Income during the year (including Tax Refund)	410 2 0
,,	Entrance Fees during the year	326 11 0
,,	Donations during the year	8 16 0
		£11884 5 7

AERONAUTICAL SOCIETY

Science Limited)

31st December, 1937.

	£ s. d.	£ s. d.
Office Furniture, Printed Books, Bindings, Old Prints, etc., at cost, less amount written off—		
Balance at 31st December, 1936	453 19 6	
Less—Amount written off	403 19 6	50 0 0
Stock of JOURNALS *and other Publications*		1 0 0
Sundry Debtors and Payments in Advance		1742 11 0
Investments at Cost—		
£1504 15s. 11d. Manchester Corporation 3 % Red. Consd. Stock, 1952/55	1518 3 3	
£3800 0s. 0d. 4½ % Conversion Loan, 1940/44 ... ... (Market Value at 31st December, 1937, £5,513)	4016 8 6	5534 11 9
Investment in and amount due from Subsidiary Company—Aeronautical Trusts Limited—		
21 Shares of 1/- each, fully paid, at cost	1 1 0	
Amount due on Current Account	146 12 6	147 13 6
Staff Pensions Fund Investment, at cost—		
£93 9s. 2d. 4½ % Conversion Loan, 1940/44		100 0 0
Cash at Bank and in Hand	... ...	1136 4 10
		£8712 1 1

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1937, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year ending 31st December, 1937.

Cr.	£ s. d.	£ s. d.
By Annual Subscriptions		4039 3 3
,, Interest on Investments (*Less* Tax)	33 17 2	
,, Interest on Deposit Account	6 17 1	
,, Income Tax Recovered	10 14 1	
,, Interest on Endowment Fund Investments (*Less* Expenses)* ...	353 8 0	404 16 4
,, Donations	... ...	500 0 0
,, Examinations—Fees Received	222 12 0	
Less Expenses	174 12 0	48 0 0
,, Garden Party—Receipts	828 17 6	
Less Expenses	769 4 6	59 13 0
,, Balance, being Excess of Expenditure over Income for Year to date, carried to Balance Sheet...		47 4 5
		£5098 17 0

(in the custody of Aeronautical Trusts Limited).

1937		£ s. d.	£ s. d.
Dec. 31.	Expenditure during the year—		
	Survey Fee on Park Street Premises	52 10 0	
	Fee *re* Recovery of Income Tax	4 4 0	
	Income paid to Aerial Science Limited*	353 8 0	410 2 0
,,	Fund at close of year...		11474 3 7
			£11884 5 7

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

	£ s. d.
To 1937 Award	5 0 0
	£5 0 0

Usborne

To Income for year carried to Balance Sheet	3 19 0
	£3 19 0

Herbert Akroyd

To Income for year carried to Balance Sheet	23 18 0
	£23 18 0

R.38

To Income for year carried to Balance Sheet	36 13 10
	£36 13 10

Edward Busk

To 1937 Award	21 0 0
	£21 0 0

Wilbur Wright

To 1937 Award	50 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	8 10 3
	£58 10 3

Simms Gold

To 1937 Awards	36 0 0
	£36 0 0

Royal Aeronautical Society

To Legal and Professional Charges	56 14 0
,, Surplus of Income over Expenditure for year transferred to Aerial Science Limited	353 8 0
	£410 2 0

TRUSTS LIMITED

FOR THE YEAR ENDED 31ST DECEMBER, 1937.

Memorial Fund.

	£ s. d.
By Interest on Investments (gross)	4 0 8
,, Balance of Expenditure over Income for year carried to Balance Sheet	0 19 4
	£5 0 0

Memorial Fund.

By Interest on Investments (gross)	3 19 0
	£3 19 0

Stuart Fund.

By Interest on Investments (gross)	23 18 0
	£23 18 0

Memorial Fund.

By Interest on Investments (gross)	36 13 10
	£36 13 10

Memorial Fund.

By Interest on Investments (*less* Tax)...	17 6 6
,, Refund of Income Tax	1 3 2
,, Balance of Expenditure over Income for year carried to Balance Sheet	2 10 4
	£21 0 0

Memorial Fund.

By Interest on Investments (*less* Tax)	53 5 9
,, Refund of Income Tax	5 4 6
	£58 10 3

Medal Fund.

By Interest on Investments (gross)	12 19 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	23 1 0
	£36 0 0

Endowment Fund.

By Interest on Investments (less Tax)	312 1 2
,, Refund of Income Tax	98 0 10
	£410 2 0

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- each	... ...	2 0 0	
Issued—21 Shares of 1/- each fully paid	... ...		1 1 0
Pilcher Memorial Fund—			
Capital Account—As at 31st December, 1936		99 14 0	
Income Account—Balance at 31st December, 1936 ...	39 5 0		
Less Excess of Expenditure over Income for year to date	0 19 4	38 5 8	137 19 8
Usborne Memorial Fund—			
Capital Account—As at 31st December, 1936		109 2 5	
Income Account—Balance at 31st December, 1936 ...	41 10 0		
Add Income for year to date	3 19 0	45 9 0	154 11 5
Herbert Akroyd Stuart Fund—			
Capital Account—As at 31st December, 1936		688 19 0	
Income Account—Balance at 31st December, 1936 ...	178 14 7		
Add Income for year to date	23 18 0	202 12 7	891 11 7
R.38 Memorial Fund—			
Capital Account—As at 31st December, 1936		978 3 10	
Income Account—Balance at 31st December, 1936 ...	358 16 10		
Add Income for year to date...	36 13 10	395 10 8	1373 14 6
Edward Busk Memorial Fund—			
Capital Account—As at 31st December, 1936		449 6 1	
Income Account—Balance at 31st December, 1936 ...	88 8 8		
Less Excess of Expenditure over Income for year to date	2 10 4	85 18 4	535 4 5
Wilbur Wright Memorial Fund—			
Capital Account—As at 31st December, 1936		1298 9 9	
Income Account—Balance at 31st December, 1936 ...	117 15 2		
Add Surplus of Income over Expenditure for year to date	8 10 3	126 5 5	1424 15 2
Simms Gold Medal Fund—			
Capital Account—As at 31st December, 1936		250 0 0	
Less—*Income Account*—			
Deficiency at 31st December, 1936	16 2 6		
Add Excess of Expenditure over Income for year to date	23 1 0	39 3 6	210 16 6
Royal Aeronautical Society Endowment Fund—			
Capital Account—Balance at 31st December, 1936 ...		11138 16 7	
Add Donations received during year		8 16 0	
Entrance Fees received during year		326 11 0	11474 3 7
			£16203 17 10

We report to the Members of Aeronautical Trusts Limited, that we have examined the above
explanations we have required. We are of opinion that the Balance Sheet is properly drawn up
December, 1937, according to the best of our information and the explanations given to us and as

3, Frederick's Place, Old Jewry, London, E.C.2.
17th February, 1938.

TRUSTS LIMITED

31st December, 1937.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	21 14 8	137 19 8
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	40 0 4	154 11 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	192 12 7	891 11 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	274 15 8	1373 14 6
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£217 London Transport 4½ % "A" Stock at cost	199 4 6	
	483 8 8	
Cash at Bank	50 12 7	
Amount due for refund of Income Tax	1 3 2	535 4 5
Wilbur Wright Memorial Fund—		
£1047 6s. 7d. 3½ % Conversion Stock, at cost	800 0 0	
£550 Canada 4 % Stock, at cost	531 10 9	
	1331 10 9	
Cash at Bank	105 12 11	
Amount due for refund of Income Tax	5 4 6	
	1442 8 2	
Less—Amount owing to Aerial Science Limited	17 13 0	1424 15 2
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	12 19 0	
	262 19 0	
Less—Amount owing to Aerial Science Limited	52 2 6	210 16 6
Royal Aeronautical Society Endowment Fund—		
Investments at cost	11199 19 3	
Cash at Bank	257 4 6	
Amount due for refund of Income Tax	98 0 10	
	11555 4 7	
Less—Amount due to Aerial Science Limited ... 76 17 0		
Amount owing for Legal Expenses 4 4 0	81 1 0	11474 3 7
Cash in Hand		1 1 0
		£16203 17 10

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

(Signed) PRICE, WATERHOUSE & CO.

REVIEWS

Aeroplane Design.

By E. W. C. Wilkins, B.Sc., A.F.R.Ae.S. Published by Charles Griffin & Co. Ltd. Price 20/-

As far as I can remember, this is the first book that I have seen for many years which has been written on aeroplane design by an author who is actually engaged in it. The Bristol Aeroplane Co. Ltd., to whose technical staff the author belongs, are well known as builders of very successful aeroplanes, the credit for which, doubtless, is partially due to his work. All this suggests that the book should be valuable.

Actually it fully realises expectations. It necessarily does not always give the derivation of the formulæ used, but it does give in a very clear form, what a modern designer has to do when he designs an aeroplane. In many cases actual calculations are given, and the whole machine is discussed in detail with methods of proportioning the various parts and, in certain cases, of calculating their strengths. All this from the point of view of a man who has actually had to do the work.

It is considered that an adequate aeronautical library for a person engaged in aeroplane design might consist of this book, a good modern work on aerodynamics, such as Dr. Piercy's, and a work on stress calculations, such as Aeroplane Structures, by Pippard and Pritchard. These three are complementary to each other, and, together, will be adequate for almost all purposes of practical design.

The Menace of the Clouds.

By Air Commodore L. E. O. Charlton, C.B., C.M.G., D.S.O. Published by William Hodge & Co. Ltd. Price 12/6.

It is unfortunate that this book is supplied with a dust cover which suggests that it is a novel of the type intended to stimulate the jaded appetite of those who revel in lurid literature, for it may stop many from reading the book who would read it if they knew what it was about.

It is actually an analysis of world strategy as it concerns the British Empire, written by an author who knows very welll what he is writing about, but who is, in a sense, an extremist in the view he takes of the potency of an air force.

He believes, for instance, that we should scrap the navy and devote the money saved to increasing our air force, and thinks that in this matter, Italy, Russia and Germany are in advance of ourselves. Another view might be that all these nations have as large navies as they can afford. Recent information suggests that Russia, who seems to posses more submarines than any other nation, is on the point of laying down a number of battleships.

He believes that much the same thing is true of the army, as he thinks that under the threat of air attack it is doubtful whether armies can be assembled, and that vital points in the communications, such as bridges will be bombed out of existence. Transport ships would be at the mercy of bombers, and the same would be true of merchant ships, while there is no really adequate method of defence.

It seems much more probable that these things will not work out in this way. Without depreciating air power, there is no evidence whatever that naval vessels are likely to be bombed out of existence. Certainly, if one is allowed to assume that bombs will hit the most vulnerable spots, even a small bomb might disable a battleship, as it would be possible to disable it with a few rifle shots if one

was allowed to put them precisely where they would do the most damage. One of our battleships at Jutland sustained some 20 hits from large calibre armour piercing shell, with the result that her fighting capacity was practically unimpaired. Would 20 bomb hits have done more damage? While battleships have improved in design since Jutland, and are much stronger than they used to be there has been no improvement in high explosives.

The amount of bombardment that armies could stand without disintegrating was shown in the last war and a much greater density of shell fire can be produced by guns than is ever likely to be produced by bombing aircraft. The aircraft has a longer range than the gun and this seems to be its only advantage.

Reports of bombing in Spain and China do not seem to have produced the effect on the civil population which is expected by the author. One lesson however, seems to be clear, that a successful air raid depends on the absence of opposition. If serious opposition is present bombing raids seem to be invariably failures.

But this book should be read. It puts a point of view which is worthy of careful study, and although it is not likely that many readers, even if they are fellow officers of the author, will accept the full implications of his views, yet there is everything to gain when such views are put forward and discussed. For this reason I would look forward to reading a book by a naval officer who might be expected to regard the importance of his own service in a similar way to that of the author and the Royal Air Force. Half-way between the two predictions might be made which would quite possibly prove to be correct.

MACHINE DRAWING FOR STUDENTS.

By F. J. Price, B.Sc. Published by Sir Isaac Pitman and Sons, Ltd. Price 7s. 6d. (Third and Enlarged Edition.)

This is the third edition of this work which is a textbook on the subject of Machine Drawing, principally intended for students of aeronautical engineering. The fact that it has attained a third edition shows that there is a demand for a book on this subject. The work itself is well written and has large numbers of diagrams intended to help the student who is learning how to read blue prints and to make engineering drawings. It is sufficient to say that they are well selected so as to illustrate many of the difficulties which have to be solved by draughtsmen. Perhaps sufficient stress has not been laid on the fact that many firms have their own conventions and, rightly or wrongly, prefer them, but the student, if he joins such a firm, will soon be guided into the desired path.

A useful book and one which can be recommended to every student of mechanics.

HANDBOOK OF AERONAUTICS.

Vol. II. Published by Sir Isaac Pitman and Sons. Price 25/-.

This volume is the third edition of the engine section of the handbook and it has been edited by Andrew Swan, B.Sc., A.M.Inst.C.E., A.F.R.Ae.S. The whole series of these volumes is published under the authority of the Royal Aeronautical Society.

It can be said that with one exception, to be referred to later, this book is a model of what a handbook should be. All chapters in the second edition have been reviewed and much has been rewritten so as to include the latest data. Its scope is complete and comprehensive, including:—Design data, performance data, stress calculations, supercharging, carburettors, cooling, ignition, fuels and fuel systems, lubricating systems and oils, exhaust systems and silencing, engine heaters and silencers, compression ignition engines, and, finally, testing. There is also an adequate bibliography, partially scattered among the text, partially given in a list at the end of the book. There are also large numbers of illustrations and graphs.

Each of the various subjects is treated more on the lines of a textbook rather than a handbook, though the proofs of the various formulæ are usually not given, and the whole work is a complete compendium of the present state of knowledge on aero engines and their accessories. The only point to which criticism can be directed is the index, which might be adequate for a textbook but which is totally inadequate for a handbook, where the reader requires to turn up small points quickly. Also the reader's first idea of where the subject will be found in the index may not coincide with the view of the indexer as to where it ought to be, and hence much time may be lost in turning over pages. It is strongly recommended that before the next volume is published that the editor should examine the index of one or more of the long established mechanical handbooks and have the new index prepared accordingly. The book is so excellent in every other respect that it is regrettable that this fault should be perpetuated.

NOTES ON SUPERCHARGING.

By C. E. Jones. Published by Sir Isaac Pitman and Sons, Ltd. Price 3s.

This book deals solely with supercharging and is intended for use by ground engineers who may have to do with engines fitted with this appliance. The use of a supercharger complicates the functioning of a petrol engine in many different directions, and there are further complications if a variable pitch airscrew is fitted.

The book deals with these matters in a way which can be commended, and should enable anyone who starts with a knowledge of engines to form a clear idea of the effect of adding a supercharger. One or two more diagrams might have been added with advantage, especially in order to show the method of arranging the supercharger and carburettor.

There are a few slips which ought not to have occurred and which should be corrected in future editions. On page 15, the capital X in the formula should, presumably, have been K, and it should be stated whether the temperature T_0 is F. or C. C. seems to be used later on. A better type for the symbol π should be available. On page 20, the formula as stated with the list of symbols is rather indeterminate; p occurs, but it is not in the symbol list, and some explanation should have been given about the derivation of the constant 792,000. For the class of reader for which this book is intended it is necessary to make everything as clear as possible.

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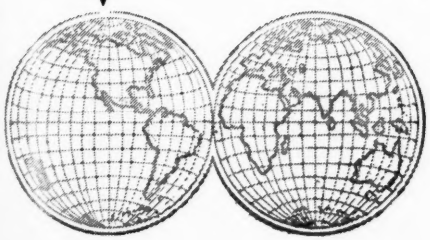

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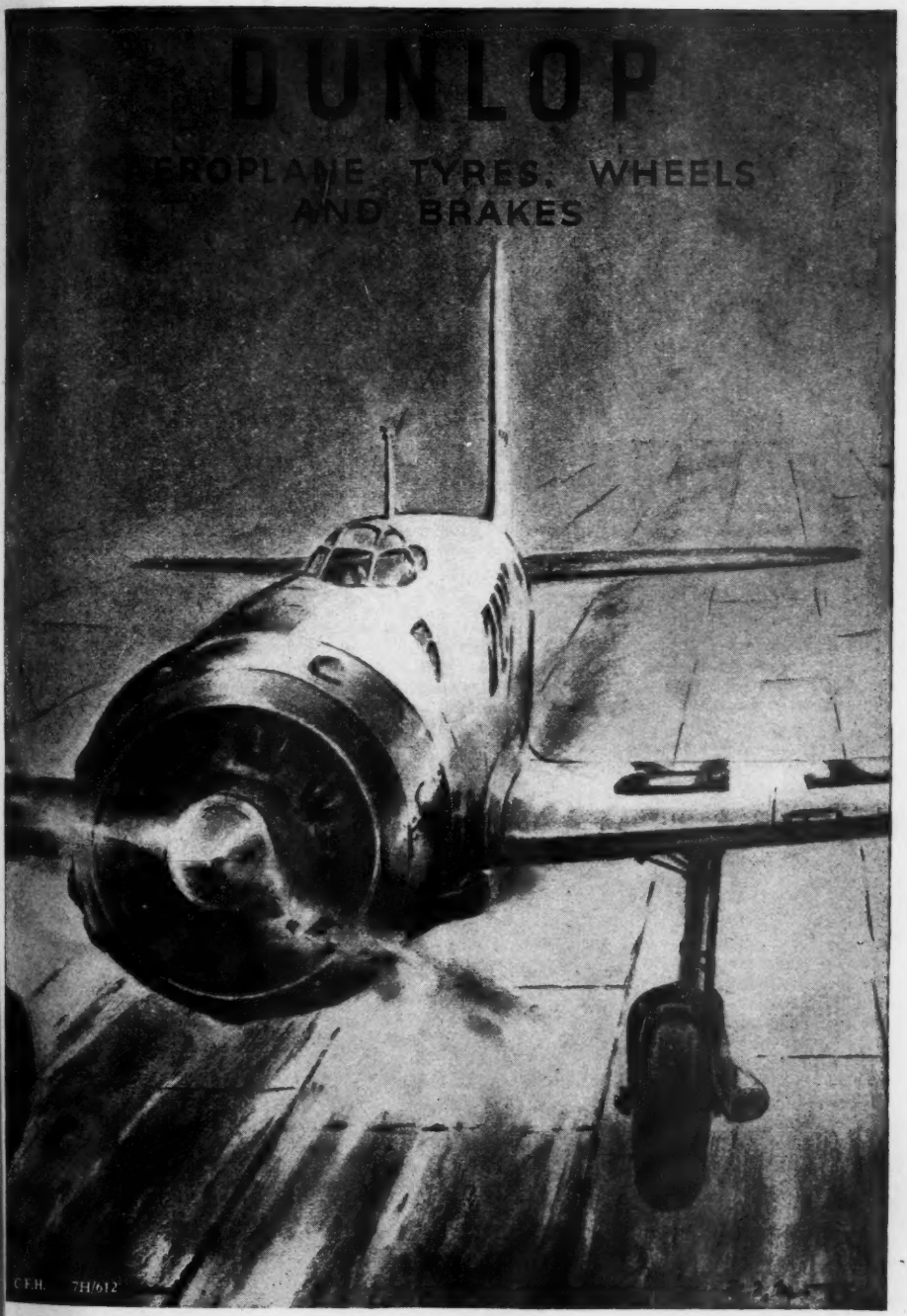
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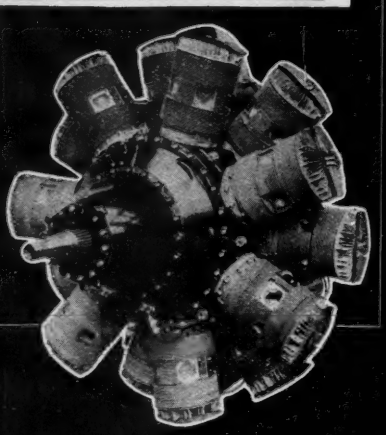

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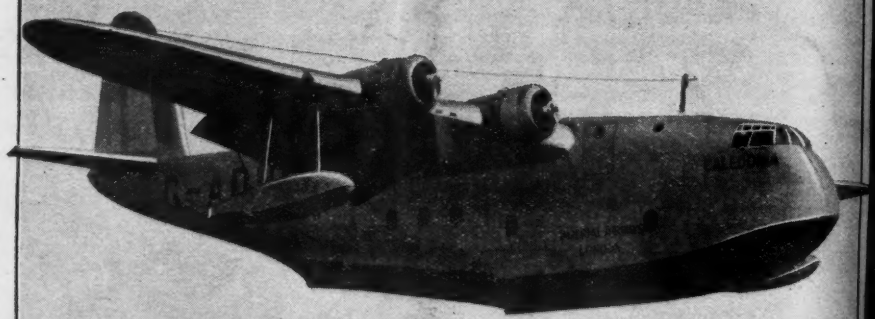

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INSTABILITY OF MONOCOQUE STRUCTURES IN PURE BENDING.

By N. J. HOFF.*

§1. INTRODUCTION.

The growing demand for aerodynamically advantageous forms, for smooth surfaces, and last but not least for a better ratio of useful cross section to total cross section of fuselages lead to an increasing application of monocoque structures in aircraft construction. Unlike ordinary beams the behaviour of such thin walled structures under loads and their ultimate failure is influenced a great deal by instability phenomena. In the present paper these problems are dealt with in some detail for the case of pure bending.

In consequence of the complexity of the problems involved several simplifying assumptions have to be made in order to render the application of analytical methods possible. The monocoque structure to be dealt with in the following is, therefore, assumed to be cylindrical and of circular cross section. It consists of a great number of uniform longitudinal stiffeners, termed stringers, and of several uniform transverse stiffeners, called rings. The whole structure is covered by a very thin sheet.[1] Though real aircraft structures differ considerably from the above model, results obtained are useful for the strength calculation of aircraft, especially of fuselages. The effect of the assumptions made is dealt with in §15 and §20.

The form of instability which is likely to occur first is the buckling of the panels between stiffeners. Since this problem is discussed in several text books in great detail a repeated treatment here was considered unnecessary.

By the wave formation of the sheet covering, the load carrying capacity of the structure and the failure of the compressed stringers are influenced a great deal. This effect is conveniently allowed for by the assumption of an effective width of sheet. In Part I of the present paper the theoretical and experimental investigations of several authors concerning this problem have briefly been outlined and the results obtained collected, compared and completed in Figs. 3 and 4. With the aid of these diagrams the effective width can be calculated on a broader basis than before, inasmuch the results of all authors concerned can be used simultaneously.[2]

Part II deals with the flattening of monocoque structures. This problem was first discussed by Brazier.[3] The result of his investigations was that every thin-walled tube flattens under the action of bending moments and the flattening ratio is proportional to the square of the curvature due to bending of the axis of the tube. As soon, however, as a critical value of the curvature is reached the tube becomes unstable and collapses by flattening. It is of great importance to know whether such instability is likely to occur and whether the flattening ratio may attain such values as to reduce materially the moment of inertia and the modulus of the section in case of monocoque structures used in aircraft construction.

* Author is very much indebted to owners and directors of Manfred Weiss Aeroplane and Motor Works, Ltd., Budapest, for their kind permission to carry out experiments at the works. further to Mr. J. Dauda for his aid at experiments, and to Mr. J. Torday, for his kindness in drawing the diagrams.

[1] In Fig. 5 such a monocoque structure is shown, but in the distorted form assumed for the calculations of Part II. See also Fig. 20.

[2] A good collection of results obtained may be found in Ref. 9. Cf. also Chap. XV., Ref. 18.

[3] V. Ref. 1.

It follows from the calculations of Part II that the stiffness of normal aircraft fuselages having rings and stringers is such that the flattening in pure bending is unimportant and that instability by flattening cannot occur. Consequently in the case of any new design these questions need not be investigated in the future unless it concerns some quite unusual construction. In this latter case the maximum value of the flattening ratio can mostly be easily calculated by the formulæ deduced in Part II.

Another form of instability, which has not as yet been often observed and discussed but in future lighter and more efficient structures will become of more importance, will be dealt with in Part III. This form, which has been observed in the experiments described in Part IV, and which is shown in Figs. 15, 23 and 24, involves the simultaneous buckling of several stringers and several rings on the compression side of the bent structure. In the present paper this form of instability has been termed the local buckling of the monocoque structure. The results of the calculations have been diagrammatically presented in Fig. 19. With the aid of this diagram the possibility of the occurrence of local buckling may be very conveniently checked in any practical case.

In order to check the above outlined calculations some preliminary tests have been carried out. These are described in Part IV. The general agreement with theoretical results concerning flattening ratio and local buckling is reasonably good. The discrepancies observed—*e.g.*, the stress at collapse by local buckling was found 33 per cent. higher than calculated—can probably be attributed to the influence of the sheet covering, though the effect of the considerable initial deviations from the true form may also be of some importance. It is believed that the discrepancy between theoretical and experimental results will turn out smaller in case of real aircraft structures. Nevertheless, for the definitive solution of the problem of local buckling a large series of experiments is needed.

In Part V a summary of results obtained is given.

Part I.

Behaviour of Stringers and Panels.

§2. The Effective Width of Sheet.

It is a well-known fact that on the compression side of monocoque structures in pure bending the sheet covering is likely to buckle long before the stringers and rings become unstable. Though after the buckling load of the panels is exceeded, the bending moment may be increased a great deal until permanent deformations appear or final collapse of the monocoque structure occurs, yet the load carrying capacity of the waved sheet covering decreases gradually with increasing load and consequently the proportionality between the load and the shortening ceases. This interesting phenomenon may best be explained in the following way.

The shortening in the load's direction is assumed to be constant over the breadth of the panel. Since the fibres adjacent to the stringers cannot buckle, their entire shortening can be only attributed to the compressive strain. At the middle of the panel, however, the fibres are free to deflect and the greatest part of the shortening is due to the curvature; the compressive strain of the middle fibres is small and generally not much in excess of the critical compressive strain of the panel. Stress and strain being proportional under the elastic limit, the stress distribution is similar to that shown by full lines in Fig. 1.

It is very convenient both for practical computations and theoretical calculations to substitute for the real stress distribution a simpler one shown by the dotted lines in Fig. 1. Thereby it is assumed that only the fibres adjacent to stringers carry the load and that the stress in that part of the sheet of the breadth $2w$ is uniform and equal to the stress in the stringers p_{str}. The remaining sheet

is considered wholly ineffective. The area $2\,wp_{str}$ must, of course, equal the shaded area of Fig. 1.

Professor von Kármán was the first to determine theoretically the breadth $2\,w$ which has been denoted the effective width of sheet, in conformity with marine engineering practice. In addition to the assumptions already quoted von Kármán supposed in his analysis that after buckling only the effective sheet is curved perpendicularly to the direction of the load and that the middle portion remains straight in such sections. By neglecting the flat and unloaded middle portion Professor von Kármán succeeded in finding an exact solution for the deflections and for the critical load of a uniformly loaded panel of the width $2\,w$ which substitutes the whole panel of the width b. The shape of the wave was found to be sinusoidal in the direction of the load and sinusoidal combined with a straight middle portion perpendicularly to the direction of the load. The

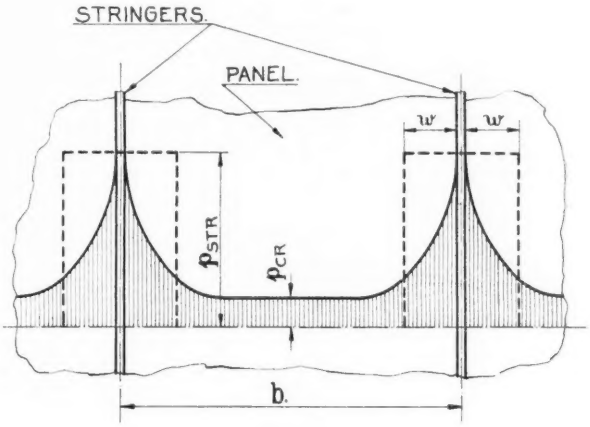

FIG. 1.

critical stress becomes a minimum when the wave length in the direction of the load is put

$$L = 2\,w.$$

With this value the effective width of the sheet becomes

$$2\,w = \{\,\pi/\sqrt{[3\,(1-\sigma^2)]}\,\} \times \sqrt{(E/p_{str})} \times t \quad . \quad . \quad . \quad (1)$$

where σ is Poisson's ratio, E Young's modulus, p_{str} the stress in the stringer and in the effective sheet and t the thickness of the sheet. With $\sigma = 0.3$ we get

$$2\,w = 1.9\sqrt{(E/p_{str})} \times t \quad . \quad . \quad . \quad . \quad (1a)$$

Because of the arbitrary assumptions for stress distribution it was suggested by Professor von Kármán and his collaborators to retain only the shape of the formula equation (1) and determine the value of the constant coefficient by experiment. An analysis of the results of tests carried out by Messrs. Shuman and Back[4] showed that the average value of the constant was 1.5 and that no systematic difference was found when applying the formula to materials as different as duralumin, stainless steel, monel metal and nickel.

It is interesting to note, however, that the value of the constant, as given correctly by the theory, is 1.9 for the case when the effective width of the sheet

[4] V. Ref. 21.

at the moment of buckling is to be determined. In this case, the value of the buckling load being, according to Messrs. Pippard and Pritchard,[5]

$$p_{cr} = 3.62\, Et^2/b^2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

equation (1*a*) becomes

$$2w = b.$$

This means that the whole breadth b is effective and the form of the deflections perpendicular to the direction of loading is a sine curve. This agreement is due to the fact that in this case the stress is distributed uniformly over the breadth $2w = b$, in conformity with assumptions.

A more detailed account of the problem as regards the effective width of sheet was given by H. L. Cox[6] who used strain energy methods in his investigations. A convenient analytical form for the deflections consistent with boundary conditions was assumed and the critical stress determined from the conditions that the strain energy stored in the panel must equal the work done by the applied forces and that the variable parameters characterising the wave form have to be chosen in such a way as to render the critical stress a minimum. Contrary to the treatment of the problem as done by Professor von Kármán no assumptions regarding the distribution of the longitudinal stresses were made.

In case of simply supported edges the wave form assumed was sinusoidal in the direction of the applied loads and consisted of a sinusoidal half wave across the width at the moment of buckling, and of a combination of sine lines with a straight middle portion, as shown in Fig. 2, when the applied load exceeded the

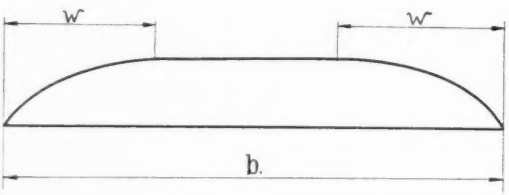

FIG. 2.

buckling load of the panel. The width of the straight middle portion was one of the parameters mentioned above. The cases when the edges parallel to the applied loads are clamped and when all four edges are clamped were also treated on ground of similar assumptions for the wave form.

One part of the calculations has been carried out graphically and a curve for each case of edge constraint has been obtained showing the load acting on the panel as plotted against the shortening of the panel. An approximate formula has also been deduced from the diagram in the form

$$2w = \alpha\sqrt{(E/p_{str})} \times t + \beta b \quad . \quad . \quad . \quad . \quad (3)$$

subject to the overriding maximum

$$2w = b \quad . \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

The values of the constants are the following:—

α	β	Unloaded edges.
1.52	0.09	Simply supported.
2.18	0.14	Clamped.

In both cases the edges parallel to the direction of the applied load are assumed to remain free to move in the plane of the panel. It is an important result of the

[5] V. p. 275, Ref. 18.
[6] V. Ref. 2.

experiments carried out by H. L. Cox that the lateral constraint imposed in actual structures seems as a rule to be negligible.

The most recent theoretical results concerning the effective width were published by K. Marguerre.[7] In his treatise the critical stress and the effective width of a panel simply supported at all four edges were calculated with aid of a combination of the exact and the strain energy methods. A very complex form was assumed for the deflections incorporating a number of secondary waves near the stringers in addition to the main wave as suggested by von Kármán and Cox.[8] Boundary conditions were carefully considered and contrary to general practice terms containing the squares of the (infinitely) small deflections perpendicular to the plane of the panel were not neglected in the calculations. The results of the

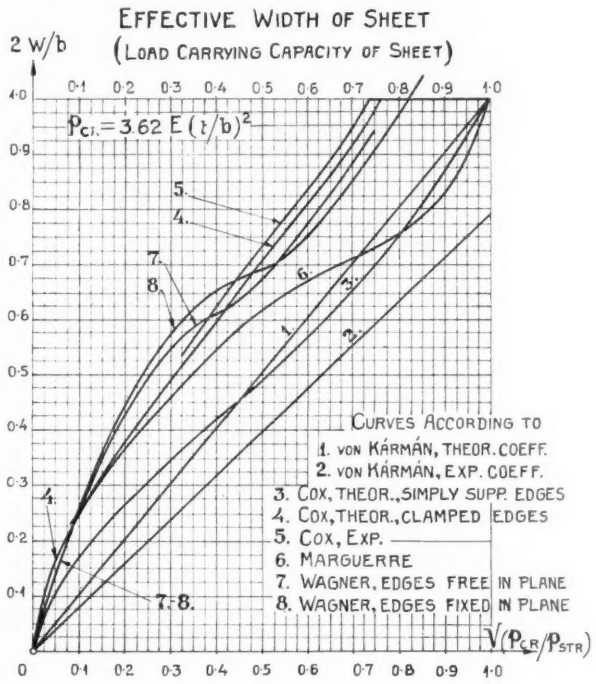

FIG. 3.

very complex mathematical computations are plotted in Fig. 3. Marguerre gave two approximate formulæ for practical computations, viz. :—

$$2w = 1.54\sqrt{(E/p_{str})} \times t + 0.19\,b \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$2w = \sqrt[3]{(p_{cr}/p_{str})} \times b \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Concerning experiments at the time of the calculations by Professor von Kármán only the results of Shuman and Back were available. In these tests the edges parallel to the applied load were supported in V-grooves approximately realising the assumptions of freely supported edges. Test pieces were compressed between

[7] V. Ref. 16.

[8] Such secondary waves have been observed by Lahde and Wagner (v. Ref. 13) in experiments where, however, the unloaded edges were clamped.

flat ends. In consequence of the fact that only the failing load was measured and thus the somewhat indefinite value of the stress at the yield point appears in the computations, results can only be compared on broad lines with theoretical calculations.

The experiments carried out at the N.P.L.[9] aimed at obtaining similar end constraint at the unloaded edges as are found in practice when the panel is riveted to stiffeners. The edges of the test pieces have, therefore, been bolted to a number of stirrups. Strains were measured during tests by extensometers of the Martens type.

In the experiments of R. Lahde and Prof. H. Wagner[10] the unloaded edges of the panels were clamped and for the greater part of test pieces held a constant distance apart. A very interesting feature of the experiments was that only the slopes of the waved sheets were recorded with aid of a specially designed device at very numerous points in two perpendicular directions, but strains in the panels were not directly measured. The form of the waves and the values of the stress were obtained from test records with aid of analytical computations. The large number of measurements established a very reliable basis for plotting a curve for the effective width of sheet under the specified conditions.

In Fig. 3 values of the effective width of sheet, as calculated or measured according to the above quoted methods, have been plotted against $\sqrt{(p_{cr}/p_{str})}$, where p_{cr} is the critical (buckling) stress of the panel

$$p_{cr} = 3.62\, E\, (t/b)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and p_{str} is the stress in the stringers.

With the aid of equation (2) von Kármán's formula can be transformed into

$$2\, w/b = \sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

when using the coefficient 1.9 in equation (1*a*), as theoretically determined by von Kármán and

$$2w/b = 0.79\sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

when using the coefficient 1.5 suggested by Sechler and Donnell[11] on the ground of Shuman and Back's experiments. In Fig. 3 both equations are represented by straight lines.

The values for the curves presenting the theoretical results of H. L. Cox have been taken from Figs. 1 and 3 of Rep. and Mem. No. 1554. It may be mentioned that in Cox's diagram any ordinate of the enveloping curve of the straight lines $\alpha = \text{const.}$ divided by the corresponding abscissa gives the value of the effective width divided by the breadth of the panel $2\, w/b$.

Marguerre's results have been replotted from the theoretical curve of Fig. 3 of his treatise[12] and do not, therefore, represent the approximate formulæ quoted above. His curve refers to a square panel simply supported at all four edges and the unloaded edges free to move in the plane of the panel.

As regards experimental data Fig. 3 contains those obtained by Cox and Lahde-Wagner. The test results of H. L. Cox have been replotted from Figs. 5 and 6 of Rep. and Mem. No. 1554. Results of Lahde-Wagner have been taken from Fig. 4 of their treatise where the method used in the present paper for plotting results was first applied. The value p_{cr} was, however, calculated by Lahde-Wagner for the case when the unloaded edges were clamped. Moreover, in the publication mentioned, the effective width refers to the stress in the edges of the panel and not in the stringer. For the convenience of comparison it is, therefore, to be multiplied by the factor

$$f = [1 + \sigma\, (e_y/e_x)]/(1 - \sigma^2).$$

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[9] V. Ref. 2.
[10] V. Ref. 13.
[11] V. Ref. 20.
[12] V. Ref. 16. It may be mentioned that Marguerre's curve has been drawn to a very small scale in the original paper and therefore could be only approximately reproduced here.

In above formula e_x is the strain in the direction of the applied load and e_y the strain perpendicular to that direction. Since with Poisson's ratio $\sigma = 0.3$ the value of the factor f is

$f = 1.1$ when the unloaded edges are held a fixed distance apart, and

$f = 1.0$ when the unloaded edges are free to move in the plane of the panel,

and the ratio of the critical stress for clamped edges to the critical stress for simply supported edges is

1.40 when the unloaded edges are held a fixed distance apart, and

1.82 when the unloaded edges are free to move in the plane of the panel,[13]

hence the ordinates of the diagram of Lahde-Wagner have to be multiplied by 1.1 and by 1.0 and the abscissæ by 0.845 and by 0.742, respectively, when the unloaded edges are held a fixed distance apart and when free to move in the plane of the panel.

From Fig. 3 the following conclusions may be drawn:—

(1) The agreement between theoretical results of Cox and experimental results of Cox and Lahde-Wagner, for the case when the unloaded edges are clamped, is sufficiently good.

(2) The difference between effective width, when the unloaded edges are held a fixed distance apart and when free to move in the plane of the panel, is immaterial.

(3) No reliable experimental data are available for the case of simply supported edges. The values found by Shuman and Back, as represented by the curve 2 of von Kármán, seem to be definitely too low.

Since in practical cases some end constraint is mostly present, Fig. 3 provides sufficient data for the calculation of the effective width in the case of combinations of plane panels and stiffeners, if the stress in the stringers does not exceed the value 100 p_{cr}. In such case the value of the effective width best suited for the given edge constraint can be conveniently taken from Fig. 3 after the value $\sqrt{(p_{cr}/p_{str})}$ has been calculated. For approximate calculations the theoretically derived very conservative formula of Professor von Kármán may also be used (*V.* equation (1*a*)). It is an interesting fact that by this formula the average stress in the panel is the geometric mean of the stress in the stringer and the critical stress of the panel:—

$$p_{mean} = \sqrt{(p_{str}\, p_{cr})} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

§3. The Strength of Stringers.

The determination of the buckling load of a stringer at the compression side of a monocoque structure in bending is a very complex problem. The value of the critical load is not only dependent upon the length of the stringer between two adjacent rings, the moment of inertia and the area of its cross section, as can be assumed exactly enough in the case of ordinary struts, but is influenced also by the thickness and curvature of the sheet covering, the spacing of the stringers, the stress conditions in adjacent panels, the pitch of riveting and the liability of the cross section of the stringer to develop other forms of instability, *e.g.*, twisting. At present, therefore, the solution can be found only by experiment.

During the last few years various methods have been developed for the practical testing of monocoque structures and a great number of test results have been collected with regard to type of failure and collapsing stress. A summary of work conducted by the Air Ministry has been given by Mr. I. J. Gerard[14] in this Journal.

One problem in this context which has been solved with the aid of analytical methods is the reinforcing effect of a flat sheet as regards the buckling of stringers. This may be best allowed for by taking into account a reduced

[13] *V.* p. 12, Ref. 2.
[14] *V.* Ref. 6.

effective width of sheet which differs from the effective width for the calculation of the load carrying capacity of the sheet determined in § 2.

The compressive load carried by a stringer and the adjacent panel may be written

$$P = eE\,(A_{str} + 2\,wt)$$

where e is the strain in the stringer, E Young's modulus of elasticity for both the stringer and the panel, A_{str} the area of the stringer, $2\,w$ the effective width of the panel and t the thickness of the panel.

If the compressive strain is increased by the infinitely small amount de, the load carried by the combination of stringer and panel becomes

$$P + dP = (e + de)\,E\,[A_{str} + 2\,(w + dw)\,t]$$

since the effective width is also dependent upon the strain.

The increment of the load is therefore

$$dP = EA_{str}\,(de) + E\,2\,wt\,(de) + eE\,2\,t\,(dw) + E\,2\,(dw)\,t\,(de).$$

The first term represents the increment of the load in the stringer. Since in the last term the product of two infinitely small values appear, it may be neglected and the rate of increment of load in the sheet becomes

$$(dP/de)_{sh} = Et\,[2\,w + ed\,(2\,w)/de] \quad . \quad . \quad . \quad (8)$$

If the load carrying capacity of the sheet were independent of the magnitude of the strain, the second term in the brackets would vanish. In fact, when the compressive load is increased, the sheet behaves in such manner as if the value of its effective width were

$$2\,w' = 2\,w + e\,[d\,(2\,w)/de] \quad . \quad . \quad . \quad . \quad (9)$$

instead of $2\,w$.

The right hand side of equation (8) is the stiffness of the sheet against compression and in the following $2\,w'$ will be denoted the reduced effective width of the sheet. Since the stability of a strut in uniform compression is characterised by its reaction against an infinitely small bending moment, the effect of which is an infinitely small increase of compressive strain at the one side and an infinitely small decrease of compressive strain at the other side of the neutral axis, the reinforcing effect against strut failure rendered by the sheet covering is given by the reduced effective width $2\,w'$ characterising the capacity of the sheet of taking over additional loads and not by the effective width $2\,w$ characterising the capacity of the sheet of carrying loads.

The essential of above considerations is to allow for the decrement with increasing compressive strain of the load carrying capacity of the waved sheet covering by reducing the value of the effective width in very similar manner to the allowance made for the deviation from Hooke's law by reducing the modulus of elasticity of the material in case of stocky struts when the critical stress exceeds the limit of proportionality.[15]

The difference between effective width and reduced effective width of sheet has not been considered by Professor von Kármán and his collaborators. When using von Kármán's formula (equation (1*a*)) the application of equation (9) leads to the expression

$$2\,w' = 1.9\sqrt{(E/p_{str})} \times t - (1/2)\;1.9\sqrt{(E/p_{str})} \times t$$

$$2\,w' = 0.95\sqrt{(E/p_{str})} \times t \quad . \quad . \quad . \quad . \quad (10)$$

or with the constant coefficient 1.5 deduced from experiment

$$2\,w' = 0.75\sqrt{(E/p_{str})} \times t \quad . \quad . \quad . \quad . \quad (10a)$$

Above equations may be transformed in similar manner as was done with von Kármán's formulæ in § 2. In this case equation (10) becomes

$$2\,w'/b = 0.5\sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad (11)$$

and equation (10*a*) becomes

$$2\,w'/b = 0.395\sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad (11a)$$

[15] V. § 3, Ref. 8.

Both expressions are represented by straight lines in Fig. 4.

In order to determine the reduced effective width of sheet according to Cox's results, equation (9) may be written in the form

$$2w' = d\,(2ew)/de \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

The enveloping curve of the straight lines $\alpha = \text{const.}$ in Figs. 1 and 3 of Rep. and Mem. No. 1554 represents the value of $2ew/be_{cr}$ as plotted against the corresponding values of e/e_{cr}. Consequently the slope of the tangent at each point of the curve equals the reduced effective width divided by the breadth of the panel $2w'/b$. These slopes have been determined for both simply supported and clamped edges and results plotted in Fig. 4.

The reduced effective width according to Marguerre has been determined in the same manner having made use of Fig. 2 of his treatise.

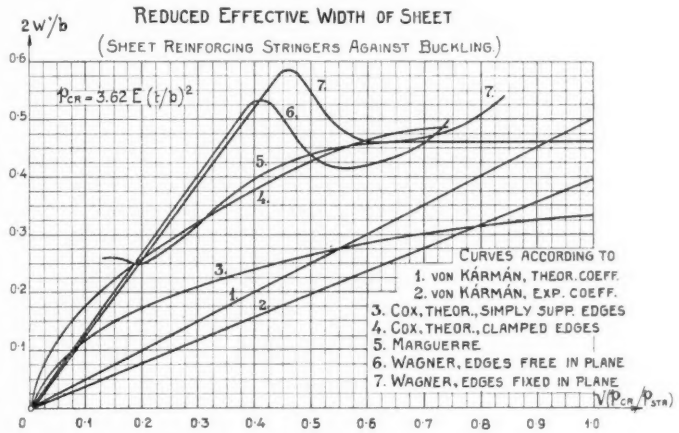

FIG. 4.

Curves 6 and 7 of Fig. 4 represent Professor Wagner's results. They have been calculated in the same way from the values of the reduced effective width curve given in Fig. 4 of the paper by Lahde-Wagner as outlined in §2 for the case of curves 7 and 8 of Fig. 3 of the present paper. Here it should be mentioned that Professor Wagner was the first to emphasise the difference between load carrying capacity of the sheet and support given by the sheet to stringers against buckling.

From Fig. 4 it may be concluded that the agreement between curves according to the different methods of calculation and experiment is not so good, as in the case of Fig. 3. It should, however, be remembered that most of these curves have been graphically determined from diagrams drawn to small scale and they cannot, therefore, be very accurate; this holds true especially for the details of the lines. The differences between values for clamped edges are, however, small enough for having confidence in making use of the curves of Fig. 4 in calculations. The curves representing von Kármán's formulæ (equations (10) and 10*a*)) are again very conservative.

§4. The Calculation of the Failing Load of Combinations of Panels and Stringers.

Though in general the failing load of a stringer at the compression side of a monocoque structure cannot be calculated with aid of purely analytical methods, it may approximately be predicted in some cases, viz., if there is evidence enough

for assuming that at collapse the stringer will buckle between two adjacent rings before any other form of instability, *e.g.*, twisting of the stringer sections, wrinkling of the outstanding ends of stringers, buckling of the sheet covering between adjacent rivets, etc., might occur. The simplest of such cases, viz., a plane or slightly curved panel reinforced by two or more stiffeners, was thoroughly analysed by Lundquist.[16] The best agreement with experiments carried out at the Massachusetts Institute of Technology was obtained when proceeding in the following way with the calculations:—[17]

(1) Assume a stress at failure; lacking other information assume the stress corresponding to the slenderness ratio of the stiffener alone.
(2) Calculate the effective width of sheet in terms of the sheet thickness using equation (1*a*).[18]
(3) With the effective width determined, obtain the slenderness ratio for the combination of stiffener and effective width of sheet.
(4) With the slenderness ratio determined obtain the stress at failure.
(5) If the stress at failure thus determined agrees with the assumed stress at failure, multiply the stress by the area of the combination. If not, assume a new stress and repeat calculation.

For convenience, Lundquist suggested to draw a column curve and also curves showing the variation of area and slenderness ratio of the combination with effective width before carrying out the above calculations. He was aware of the fact that the form factor for the combination differed from that for the stiffener alone when calculating column failure; the difference is, however, small.

On ground of §3 it is apparent that the effective width according to equation (1*a*) must not be taken into account when calculating strut failure. It is, therefore, very interesting to check whether or not the procedure suggested by Lundquist agrees with experiments in the case when in a correct way the reduced effective width is used.

The corrected procedure may be summarised as follows:—[19]

(1) Calculate the critical stress p_{cr} of the sheet according to equation (2).
(2) Assume the stress p_{str} in the stiffener at failure.
(3) Determine the value $\sqrt{(p_{cr}/p_{str})}$.
(4) Take the value of $2w'/b$ from Fig. 4. The curve best suited to edge-conditions should be used. Calculate the reduced effective width $2w'$.
(5) Calculate the reduced area and the reduced radius of gyration of the combination sheet-stiffener. Better take these values from charts previously established for the stiffener sections and sheet thicknesses frequently used.
(6) Determine the slenderness ratio of the combination.
(7) Compute by some reliable formula the failing stress of the stiffener or take the value from a strut chart. For simplicity's sake assume that the strut chart for the combination is identical with that for the stiffener alone.
(8) Compute the failing load P of the combination by multiplying the failing stress according to (7) by the reduced area of the combination according to (5).
(9) Take the value of $2w/b$ according to the value of $\sqrt{(p_{cr}/p_{str})}$ calculated under (3) from Fig. 3. The curve best suited to edge-conditions should be used. Calculate the effective width $2w$.

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[16] V. Ref. 14.
[17] Cf. also Ref. 23.
[18] Lundquist assumed 1.7 for the constant coefficient.
[19] This procedure differs mainly from that suggested by Professor Wagner—in addition to the form of presentation—by the possibility of selecting a suitable value from the curves plotted in Figs. 3 and 4 instead of using the experimental curves of Wagner alone.

(10) Calculate the area of the combination stiffener plus effective width of sheet or take the value from the chart mentioned under (5).

(11) Determine the stress in the combination by dividing the load P according to (8) by the area according to (10).

(12) If the stress calculated under (11) is in agreement with the stress p_{str} assumed according to (2), the load P according to (8) is the failing load of the combination stiffener plus effective sheet. If not, repeat calculation with a corrected value for p_{str}.

It may be mentioned that calculations according to the above scheme are not at all lengthy if the chart for area and radius of gyration of the combinations are at hand. Especially the trial and error method outlined is well convergent and two or three steps are always sufficient for getting a close approximation.

On the ground of the above method the calculations of Lundquist have been repeated. In computations curves 2 of Figs. 3 and 4, representing von Kármán's formula with the constant coefficient suggested by Sechler and Donnell, have been used. The charts for area and radius of gyration and the strut chart for flat ends, presented in Lundquist's treatise, have been retained and Lundquist's suggestion for calculating the effective width of sheet supported on three edges only, viz., that such sheet carries 0.355 times the load sustained by a sheet supported on all four edges, has been adopted.

Since in the experiments at the M.I.T. the edges of the panels were riveted to the stringers, panels were neither simply supported, nor perfectly clamped. For getting a further comparison, calculations have also been carried out on the assumption of clamped edges. In these computations the average of the values given by both experimental curves of Professor Wagner has been used.

Calculations have been carried out for six test pieces of the M.I.T. and results obtained are summarised below :—

Thickness of sheet, in. ...	0.019	0.019	0.019	0.052	0.052	0.052
Number of stiffeners	2	3	4	2	3	4
Failing load in lb. :—						
(*a*) According to the corrected method :—						
(1) Simply supp. edges	3400	5100	6800	2920	4510	6100
(2) Clamped edges ...	3760	5715	7720	3565	5010	—
(*b*) According to Lundquist's method	3620	5480	7340	3300	5090	6880
(*c*) From test results :—						
1st test	3300	5000	6500	3350	4650	6580
2nd test...	3100	5300	7100	2920	4890	6660
Average of both tests...	3200	5150	6800	3135	4770	6620

Though any importance attributed to small differences between observed and predicted loads is, as already mentioned by Lundquist, not justified, because the tests were made with indefinite end conditions, viz., flat ends, yet the following conclusions may be drawn from a comparison of above values :—

(1) The differences between calculated failing loads according to Lundquist and according to the corrected method suggested in the present paper are relatively small.

(2) The differences between calculated failing loads for simply supported and for clamped edges are moderate.

The smallness of the differences mentioned under (1) and (2) is caused in case of thin sheet by the unimportance of the share in load of the sheet, in case of thick sheet by the fact that the radius of gyration of the combination decreases, the slenderness ratio increases and the buckling stress, therefore, decreases with increasing effective width of sheet.

(3) The failing load predicted by Lundquist's method is greater than the experimental value which lies mostly between both values calculated for simply supported edges and clamped edges according to the corrected method.

It may, therefore, be stated that the failing load of flat sheet and stiffener combinations in compression may be approximately predicted according to the corrected method summarised in the 12 points above. The values of the effective width and of the reduced effective width may be taken with sufficient accuracy from Figs. 3 and 4 selecting the curves in best accordance with edge conditions.

According to Lundquist slightly curved panels carry 10—15 per cent. less than flat ones. This is caused partly by the smaller increment of the moment of inertia of the stiffener plus effective sheet due to the smaller distance of the fibres of the effective sheet from the centroid of the stiffener section, partly by the inavoidable deviations from the true shape of the sheet, which turn out greater with curved panels.

Ebner[20] suggested the following formula for the calculation of the effective width in case of curved sheet and stiffener combinations:—

$$2w = 2\bar{w} + (p_{curved}/p_{str})(b - 2\bar{w}) \quad . \quad . \quad . \quad (13)$$

In this equation the value of $2\bar{w}$ may be taken from Fig. 3 when substituting p_{str}-p_{curved} for p_{str} in the expression $\sqrt{(p_{cr}/p_{str})}$, where p_{cr} is the critical stress of the flat sheet as quoted in equation (2) and p_{curved} is the practical critical stress of a cylinder of equal curvature which may be written in the form

$$p_{curved} = 0.3\,E\,(t/r) \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where t is the thickness and r the radius of curvature of the sheet.

By the above formulæ it has been assumed that at a given stress p_{str} in the stiffener the curved sheet carries the same load as a flat sheet at the edges of which the stress equals p_{str}-p_{curved} plus the load which can be sustained by the curved sheet alone. This method of calculation was found to give reasonably good agreement with experiments carried out at the D.V.L.

Part II.

The Flattening of Monocoque Cylinders.

§5. Nature of the Problem.

It is known from both theoretical and experimental investigations that St. Venant's assumption on the constancy of the shape of the cross section of girders in pure bending does not hold true in case of thin-walled sections. The greater flexibility than calculated according to ordinary bending theory of initially curved tubes, as experimentally found by Professor Bantlin, was perfectly explained by Professor von Kármán[21] in 1911 on the assumption of a flattening of the section.

In 1927 Brazier[22] with the aid of the variational method determined exactly that the shape of an originally circular thin-walled bent cylinder corresponding to the least potential energy is quasi elliptical and that the cross section of the cylinder, therefore, must flatten, even if the centre line of the cylinder was originally straight. In consequence of the flattening St. Venant's linear law for the curvature loses its validity and the curvature increases more rapidly than the bending moment. For a certain value of the curvature the bending moment is a maximum, and after this value was reached the curvature increases even if the applied moment remains unchanged or decreases, fulfilling thereby the criterion of instability. This instability occurs when the rate of flattening, *i.e.*, the maximum radial displacement of any point of the circumference of the tube divided by the original radius of the tube, will equal 2/9.

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[20] V. Ref. 4.
[21] V. Ref. 11. Cf. also p. 70 of Ref. 5.
[22] V. Ref. 1.

In his experiments carried out with celluloid tubes Brazier in fact observed the flattening of the cross section, yet the tube always collapsed into a multi-lobed and not into the quasi-elliptical form, though the value of the bending moment corresponding to instability was close to that predicted by the theory.

For design purposes it is most important to know whether such instability is likely to occur or whether the ratio of flattening may attain values large enough to reduce materially the moment of inertia and the modulus of the section in case of monocoque structures used for aircraft fuselages and wings which differ from the tube analysed by Brazier inasmuch as they always are reinforced by transverse rings and longitudinal stringers.

In this part of the present paper the above problem will be dealt with; it will be shown that in normal aircraft structures the flattening is always negligibly small and can never attain the value corresponding to instability in accordance with theory.

§6. Method of Calculation.

Since the structure to be examined consists, as outlined in §1, of stringers and rings covered by thin sheet, it is much too complex for being analysed by the exact method used by Brazier. The approximate method, therefore, developed by Raleigh, Ritz, Timoshenko, has been used instead and calculations have been carried out in a way similar to that in which Professor von Kármán examined the flattening of curved tubes. This method involves the assumption of a convenient form for the deflections incorporating one or more arbitrary constants.

The strain energy stored in the structure and the work done by the applied loads during distortions have to be determined. The minimum of their sum can be calculated by the variation of the constants and the values for the constants found thereby determine the real distorted shape of the structure. If this variation can be carried out in such a way that the points of application of the external loads do not move, the above calculations will be reduced so that only the determining of the values of the constants which render the strain energy alone a minimum will be necessary.

This method is approximate, since by variation of the constants only the minimum of the strain energy consistent with the assumptions made for the distorted shape of the structure can be obtained. It becomes exact by assuming an infinite Fourier series for the deflections every term of which has to be regarded. Evidence enough has been, however, collected to prove that the difference between results of the exact and of the approximate method is small if the distorted shape assumed does not deviate very much from the true form. In such case, therefore, the approximate method can be used with confidence.

After having obtained the constants of the equations for the distorted shape of the structure the curvature corresponding to any given applied moment may be calculated by equating the strain energy stored in the structure to the work done by the external moments. In the general case, however, the expression obtained for the work of the applied moments being too complex for convenient calculations, the curvature will be only determined for some special cases.

For the deflections of the rings the same quasi-elliptical shape has been assumed which was obtained by Brazier with the aid of the exact method for the thin-walled tube.[23] It has been found convenient to retain the same equation for the distorted shape also for sections of the cylinder between rings, but with a different coefficient, which is variable with x as shown in Fig. 5. In case of a great number of very closely spaced rings or in case of perfectly rigid stringers, above assumptions, therefore, represent the true shape of the structure. In case of widely spaced rings and flexible stringers an infinite trigonometric series should

[23] The very small term representing St. Venant's displacement in Brazier's calculations has been neglected.

be used for describing the deflections, and expressions given in equations (16) and (17) may be regarded the first terms of these series. Nevertheless distortions, as already mentioned in §5, of real aircraft structures always being small, omission of the further terms may not influence too much the results.

These conclusions, however, do not hold good if the critical load is to be determined, the distortions in this case being much greater. Since, however, the aim of the present paper is not to determine exactly the distorted shape of the structure, but to provide an approximate formula for estimating the greatest possible deflections and to show that the instability described by Brazier cannot occur in the case of practical monocoque structures, the above assumptions for distortions may be regarded as sufficiently accurate for the purposes mentioned.

QUASI-ELLIPTICAL DISTORTIONS.

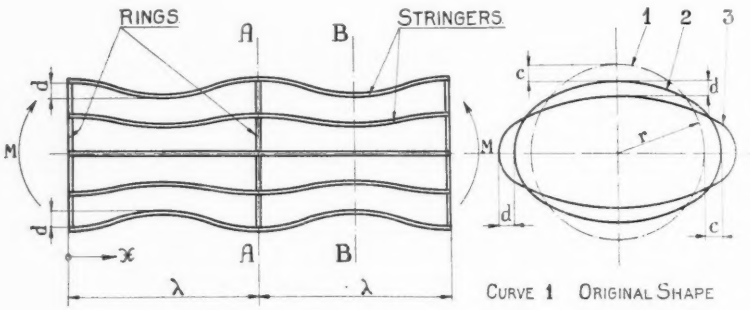

FIG. 5.

§7. DISTORTIONS OF RINGS.

In the following the total displacement of any point of the rings of the monocoque cylinder will be given, in accordance with the calculations of von Kármán and Brazier, by its two perpendicular components, viz., by the radial displacement w_r and the tangential displacement w_t.[24] The notation and the sign convention used for co-ordinates and displacements may be seen from Fig. 6.

Since the stretching of the rings affords much more strain energy than the bending, deformations may be assumed inextensional.[25] In such case radial and tangential displacements are interdependent, as it will be shown with the aid of Fig. 7.

The original length of the infinitely small arc dL_1 was

$$dL_1 = r d\phi.$$

After deformations this becomes

$$dL_2 = (r + w_r)\, d\phi + w_{t2} - w_{t1}.$$

The increment is therefore

$$dL_2 - dL_1 = w_r d\phi + dw_t$$

and the condition for inextensional deformations is consequently

$$w_r d\phi + dw_t = 0$$

or

$$w_r = -dw_t/d\phi \qquad (15)$$

[24] The longitudinal (axial) displacement is much smaller and may, therefore, be neglected, as it will be shown later.

[25] V. p. 5 of Ref. 1.

It will be assumed that the tangential displacement of any point of the rings is given by the equation

$$w_t = -(\tfrac{1}{2})\, c \sin(2\phi) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Then the radial displacement may be calculated with the aid of equation (15)

$$w_r = c \cos(2\phi) \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

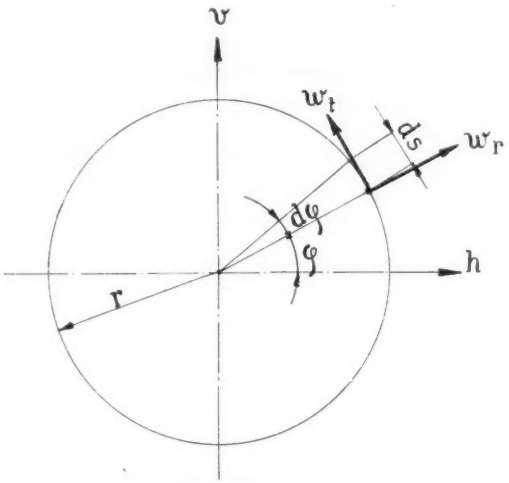

FIG. 6.

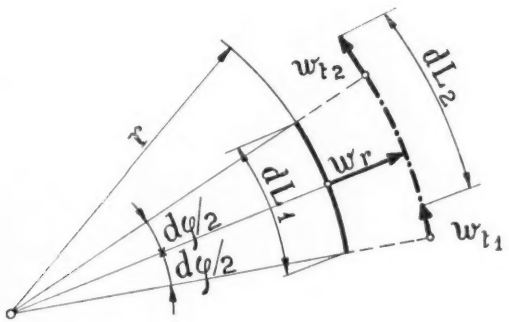

FIG. 7.

Equations (16) and (17) have also been used by Brazier and von Kármán. The deformed shape determined thereby is, as it may be easily verified, quasi-elliptical, the horizontal diameter being $d_h = 2(r+c)$ and the vertical diameter $d_v = 2(r-c)$.

The strain energy stored in an element of the bent ring is

$$dW_r = (\tfrac{1}{2})\, M \Delta d\phi \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where M is the bending moment acting on the ring element and $\Delta d\phi$ the difference between the angles $d\phi$ after and before application of the moment:—

$$\Delta d\phi = d\phi_2 - d\phi_1.$$

Notations may be found in Fig. 8.

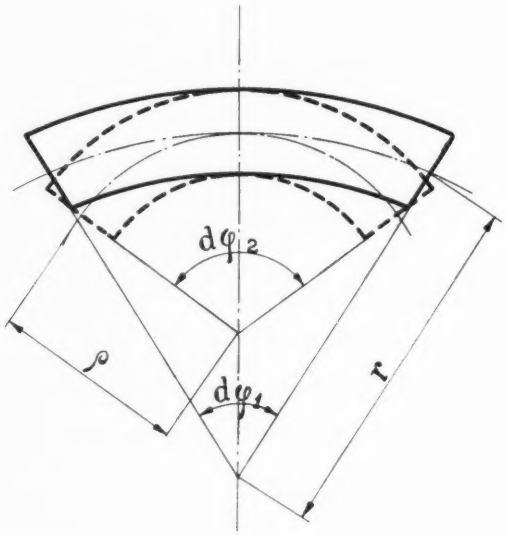

FIG. 8.

In consequence of the assumption of inextensional deformations the length of the neutral axis of the ring element must remain unaltered:—

$$\rho d\phi_2 = r d\phi_1 = dL.$$

Hence

$$\Delta d\phi = [(1/\rho) - (1/r)]\, dL \quad . \quad . \quad . \quad . \quad (19)$$

On the other hand this angle may be calculated, on the assumptions of St. Venant supposed to hold true in case of the bending of the ring, from equation

$$\Delta d\phi = M dL / E I_r \lambda$$

where E is Young's modulus of elasticity of the material and I_r the moment of inertia of the cross section of the ring divided by the distance λ between the rings.[26]

Hence

$$M = E I_r \lambda\, [(1/\rho) - (1/r)] \quad . \quad . \quad . \quad . \quad (20)$$

From equations (18), (19) and (20 we get

$$dW_r = (\tfrac{1}{2})\, E I_r \lambda\, [(1/\rho) - (1/r)]^2\, dL \quad . \quad . \quad . \quad (21)$$

The curvature $(1/\rho)$ of a curve given in polar co-ordinates R, ϕ, may be calculated by the formula

$$(1/\rho) = [R^2 + 2\,(dR/d\phi)^2 - R\,(d^2R/d\phi^2)]/[R^2 + (dR/d\phi)^2]^{3/2}.$$

[26] This notation has been introduced for getting results in a convenient form in the following paragraphs. Consequently the moment of inertia of the ring is given by the product $I_r\lambda$.

In our case we get after substitution of $r+w_r$ for R and by neglecting the products and powers of w_r which are of the second order infinitely small

$$(1/\rho)=(1/r)^2\,[r-w_r-(d^2w_r/d\phi^2)] \quad . \quad . \quad . \quad (22)$$

With the aid of equation (17) we get

$$d^2w_r/d\phi^2=-4\,c\cos(2\,\phi)$$

and

$$(1/\rho)=(1/r)\,[1+3\,(c/r)\cos(2\,\phi)] \quad . \quad . \quad . \quad (23)$$

By substituting $(1/\rho)$ as given in equation (23) into equation (21) we get

$$dW_r=(9/2)\,EI_r\lambda\,(1/r)^2\,(c/r)^2\cos^2(2\,\phi)\,dL.$$

With $dL=rd\phi$ the total strain energy stored in the ring becomes

$$W_r=(9/2)\,EI_r\,(\lambda/r)\,(c/r)^2\int_0^{2\pi}\cos^2(2\,\phi)\,d\phi.$$

Since

$$\int_0^{2\pi}\cos^2(2\,\phi)\,d\phi=\pi$$

we get

$$W_r=(9\,\pi/2)\,(\lambda/r)\,(c/r)^2\,EI_r \quad . \quad . \quad . \quad . \quad (24)$$

In order to determine the distorted shape of the cylinder the first differential coefficient of above expression with respect to c/r will be needed:—

$$\partial W_r/\partial\,(c/r)=9\,\pi EI_r\,(\lambda/r)\,(c/r) \quad . \quad . \quad . \quad (24a)$$

§8. Distortions of Stringers.

In §6 the distortions of the cylindrical monocoque structure have been dealt with and in Fig. 5 the shape of the cylinder under loads has been drawn. The simplest function representing this shape is given by

$$w_t=-(\tfrac{1}{2})\,\bar{c}\sin(2\,\phi) \quad . \quad . \quad . \quad . \quad (25a)$$

and

$$w_r=\bar{c}\cos(2\,\phi) \quad . \quad . \quad . \quad . \quad . \quad (25b)$$

where

$$\bar{c}=c+(d/2)-(d/2)\cos(2\,\pi x/\lambda) \quad . \quad . \quad . \quad (25c)$$

According to above formulæ the greatest deflections occur mid-way between rings where the horizontal diameter of the quasi-elliptical section becomes $d_h=2\,(r+c+d)$ and the vertical diameter $d_v=2\,(r-c-d)$.

As may be seen from above equations every originally straight stringer is bent in both radial and tangential directions. In case the principal axes of inertia of the cross section of the stringers are directed, as it is common practice, radially and tangentially, the strain energy stored in the stringers due to bending may be calculated separately for both directions. For simplicity it will be assumed that there is an infinitely large number of stringers distributed continuously over the circumference of the cylinder. Since in real monocoque structures the number of stringers is always great, the above assumption does not restrict appreciably the applicability of results obtained.

The curvature $(1/\rho)$ of a curve given in rectangular co-ordinates x, y, may be calculated by the formula

$$(1/\rho)=(d^2y/dx^2)/[1+(dy/dx)^2]^{3/2}.$$

In case of a slightly deflected originally straight beam $(dy/dx)^2$ can be neglected against unity, whence

$$(1/\rho)=d^2y/dx^2.$$

The curvature of the stringer in radial and tangential directions becomes, therefore, with $y = w_r$ and $y = w_t$, respectively,

$$(1/\rho_r) = d^2 w_r / dx^2 = (d/2)(4\pi^2/\lambda^2)\cos(2\pi x/\lambda)\cos(2\phi)$$
$$(1/\rho_t) = d^2 w_t / dx^2 = -(1/2)(d/2)(4\pi^2/\lambda^2)\cos(2\pi x/\lambda)\sin(2\phi).$$

Denoting by $I_{str \cdot r}$ the moment of inertia of the stringer against bending in radial direction, divided by the distance between stringers, and likewise by $I_{str \cdot t}$ the corresponding value in tangential direction, we get the following expressions for the strain energy stored in the whole structure between adjacent rings due to radial bending of the stringers:—

$$W_{str \cdot r} = \int_0^{2\pi} \int_0^{\lambda} (1/2)\, E I_{str \cdot r} (1/\rho_r)^2\, dx r d\phi$$

and due to tangential bending of the stringers

$$W_{str \cdot t} = \int_0^{2\pi} \int_0^{\lambda} (1/2)\, E I_{str \cdot t} (1/\rho_t)^2\, dx r d\phi.$$

After substituting $(1/\rho)$ from the equations quoted above and integrating we get with aid of the definite integrals

$$\int_0^{\lambda} \cos^2(2\pi x/\lambda)\, dx = \lambda/2$$

$$\int_0^{2\pi} \cos^2(2\phi)\, d\phi = \pi$$

$$\int_0^{2\pi} \sin^2(2\phi)\, d\phi = \pi$$

the following expressions for the strain energy

$$W_{str \cdot r} = \pi^5 E I_{str \cdot r} (d/r)^2 (r/\lambda)^3$$

and

$$W_{str \cdot t} = (1/4)\, \pi^5 E I_{str \cdot t} (d/r)^2 (r/\lambda)^3.$$

The whole strain energy stored in the structure between adjacent rings due to bending of the stringers is therefore

$$W_{str} = \pi^5 E I_{str} (d/r)^2 (r/\lambda)^3 \quad . \quad . \quad . \quad . \quad (26)$$

where I_{str} denotes the following expression:—

$$I_{str} = I_{str \cdot r} + (1/4)\, I_{str \cdot t} \quad . \quad . \quad . \quad . \quad (26a)$$

The differential coefficient of equation (26) with respect to (d/r) is

$$\partial W_{str}/\partial (d/r) = 2\pi^5 E I_{str} (d/r) (r/\lambda)^3 \quad . \quad . \quad . \quad (26b)$$

§9. Longitudinal Stresses.

The deflections of the stringers have been assumed symmetrical with respect to the horizontal plane containing the axis of the monocoque cylinder. Consequently the resultant of the bending moments which cause the stringers to deflect vanishes and the whole external bending moment must be resisted by the longitudinal stresses in the stringers and in the sheet covering which latter will, however, be neglected for the present.

For the convenience of the following calculations the stringers which in the preceding paragraphs have already been assumed continuously distributed will be replaced by a cylindrical sheet having a radius r equal to the distance of the stringers from the axis of the monocoque structure. The thickness t_L of the sheet substituting the stringers must be so chosen that the moment of inertia of

the sheet be equal to the moment of inertia of the stringers with respect to the horizontal axes of the sections of the cylinder.

The longitudinal stresses will be calculated on the assumption that plane sections before bending remain plane after bending, which gives a linear law. The displacements, however, of the points of the circumference due to the distortion of the whole structure must not be neglected.

The vertical displacement of any point is (*cf.* Fig. 6)

$$w_v = w_r \sin\phi + w_t \cos\phi.$$

Substituting the values for w_r and w_t as given by equations (25*a*) and (25*b*) we get after several trigonometrical transformations

$$w_v = -\bar{c} \sin^3\phi.$$

The vertical distance of any point of the circumference from the horizontal axis is therefore

$$r + w_v = \sin\phi\,(r - \bar{c}\sin^2\phi) \quad . \quad . \quad . \quad . \quad (27)$$

In conformity with the above assumptions we get for the strain

$$e = \sin\phi\,(r - \bar{c}\sin^2\phi)\,(d\Delta\alpha/dx)$$

where $d\Delta\alpha$ is the angle enclosed after bending by two sections of the cylinder distant dx (V. Fig. 9).

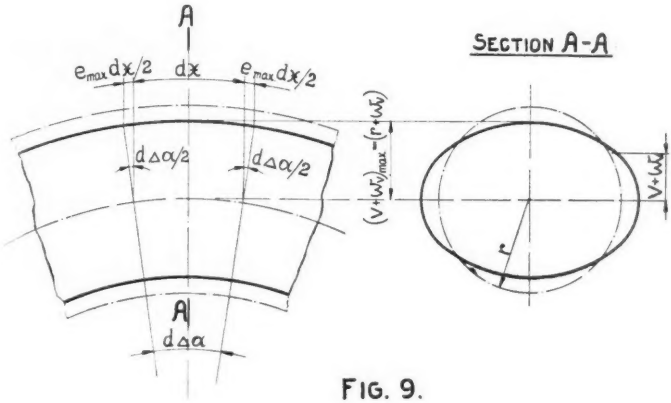

FIG. 9.

The total strain energy due to longitudinal stresses is therefore

$$W_L = (\tfrac{1}{2})\,E \int \sin^2\phi\,(r - \bar{c}\sin^2\phi)^2\,(d\Delta\alpha/dx)^2\,dV \quad . \quad . \quad (28)$$

where dV denotes an element of volume of the cylindrical sheet substituting the stringers and the integral is extended over the whole volume of the cylindrical sheet.

Since in the following the strain energy itself will not be needed, only its derivatives with respect to (c/r) and (d/r), it is convenient to differentiate equation (28) before integrating. In this equation $(d\Delta\alpha/dx)$ is variable with x in consequence of the non-uniform flattening of the cylinder which causes the moment of inertia of the section to change, while the external moment remains a constant. For the variation of the strain energy, however, $(d\Delta\alpha/dx)$ can be held unchanged at any section with the effect that the applied moments do not do any work, as outlined in §6.

The differential coefficients of equation (25*c*) are

$$\partial\bar{c}/\partial c = 1$$

$$\partial\bar{c}/\partial d = (\tfrac{1}{2})\,[1 - \cos(2\pi x/\lambda)].$$

Therefore equation (28) becomes

$$\partial W_L/\partial c = -E\int \sin^4\phi\,(r-\bar{c}\sin^2\phi)\,(d\Delta\alpha/dx)^2\,dV.$$

With the assumption of a uniform stress over the small thickness of the sheet and with aid of the definite integrals

$$\int_0^{2\pi}\sin^4\phi d\phi = (\tfrac{3}{4})\,\pi$$

$$\int_0^{2\pi}\sin^6\phi d\phi = (\tfrac{5}{8})\,\pi$$

integration of above equation with respect to dt_L and $d\phi$ gives

$$\partial W_L/\partial c = -EI_L\int_0^{\lambda}(d\Delta\alpha/dx)^2\,[(\tfrac{3}{4})-(\tfrac{5}{8})\,(\bar{c}/r)]\,dx \quad . \quad . \quad (29)$$

where I_L denotes the moment of inertia of the section with respect to the horizontal axis, divided by the radius of the cylinder[27]

$$I_L = r^2 t_L \pi \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

Before integrating with respect to x the value of $(d\Delta\alpha/dx)$ has to be determined which must not be regarded a constant when calculating the strain energy stored in the structure. Since with aid of equation (27) the moment of inertia I of any section of the distorted cylinder may be put

$$I = \int_0^{2\pi}\sin^2\phi\,[r-\bar{c}\sin^2\phi]^2\,t_L r d\phi$$

we get after integration and omission of the term containing the square of $\bar{c}$ which is of the second order:—

$$I = rI_L\,[1-(3/2)\,(\bar{c}/r)] \quad . \quad . \quad . \quad . \quad (31)$$

where I_L is the moment of inertia of the original section divided by the radius of the cylinder, as given by equation (30).

Since

$$(d\Delta\alpha/dx) = M/EI$$

the square of this expression becomes after substitution of equation (31)

$$(d\Delta\alpha/dx)^2 = M^2/E^2r^2I^2_L\,[1-3\,(\bar{c}/r)]$$

having neglected the term containing the square of $(\bar{c}/r)$. Substituting above expression in equation (29) we get

$$\partial W_L/\partial c = -(1/r)^2\,(M^2/EI_L)\int_0^{\lambda}\{\,[(\tfrac{3}{4})-(\tfrac{5}{8})\,(\bar{c}/r)]/[1-3\,(\bar{c}/r)]\,\}\,dx$$

$$= -(1/r)^2\,(M^2/EI_L)\int_0^{\lambda}[(\tfrac{3}{4})+(13/8)\,(\bar{c}/r)]\,dx.$$

With

$$\int_0^{\lambda}\cos\,(2\,\pi x/\lambda)\,dx = 0$$

we get after substitution of $\bar{c}$ from equation (25c), integration and some transformations

$$\partial W_L/\partial\,(c/r) = -(\lambda/r)\,(M^2/EI_L)\,[(\tfrac{3}{4})+(13/8)\,(c/r)+(\tfrac{13}{16})\,(d/r)] \quad . \quad (32)$$

[27] Cf. footnote 26.

In a similar way we get for the differential coefficient of the strain energy due to longitudinal stresses with respect to (d/r)

$$\partial W_L/\partial (d/r) = -(\tfrac{1}{2})\,(\lambda/r)\,(M^2/EI_L)\,[(\tfrac{3}{4}) + (13/8)\,(c/r) + (39/32)\,(d/r)] \qquad (33)$$

§10. Determination of Deflections.

The total strain energy stored in the bent structure may be put

$$W_{tot} = W_r + W_{str} + W_L + W_{sh} \quad . \quad . \quad . \quad . \quad . \quad (34)$$

where the values of W_r, W_{str} and W_L have been calculated in the preceding paragraphs and W_{sh} is the strain energy stored in the sheet covering which has been neglected. The effect of the omission will be dealt with later.

The expressions for the strain energy contain two parameters, viz., c and d, which determine the distorted shape of the structure. They have to be so chosen as to render the total strain energy a minimum, as has been discussed in §6.

The first condition of W_{tot} being a minimum is therefore

$$\partial W_{tot}/\partial (c/r) = 0$$

if differentiating with respect to (c/r) instead of c for getting results in a more convenient form.

$\partial W_{str}/\partial (c/r)$ being zero we get with aid of equations $(24a)$ and (32)

$$9\,\pi E I_r\,(\lambda/r)\,(c/r) = (\lambda/r)\,(M^2/EI_L)\,[(\tfrac{3}{4}) + (13/8)\,(c/r) + (\tfrac{13}{16})\,(d/r)] \qquad (35)$$

In case of small deflections the terms containing (c/r) and (d/r) may be neglected against $(\frac{3}{4})$. In this case the deflections of the rings are independent of the deflections of the stringers :—

$$(c/r) = (1/12\,\pi)\,(1/I_L I_r)\,(M/E)^2 \quad . \quad . \quad . \quad (35a)$$

The second condition of W_{tot} being a minimum is

$$\partial W_{tot}/\partial (d/r) = 0.$$

Since $\partial W_r/\partial (d/r) = 0$, we get with aid of equations $(26b)$ and (33)

$$2\,\pi^5 E I_{str}\,(d/r)\,(r/\lambda)^3 = (\tfrac{1}{2})\,(\lambda/r)\,(M^2/EI_L)\,[(\tfrac{3}{4}) + (13/8)\,(c/r) + (39/32)\,(d/r)] \quad . \quad . \quad . \quad . \quad . \quad (36)$$

By neglecting the terms containing (c/r) and (d/r) against $(\frac{3}{4})$ the deflections of the stringers become independent of the deflections of the rings :—

$$(d/r) = (\tfrac{3}{16}/\pi^5)\,(\lambda/r)^4\,(1/I_L I_{str})\,(M/E)^2 \quad . \quad . \quad . \quad (36a)$$

In case of very small deflections the moment of inertia of any section of the structure will but very slightly differ from the original value and the curvature of the axis of the cylinder may, therefore, be put with sufficient accuracy

$$(1/\rho) = (d\Delta\alpha/dx) = (\Delta\alpha/\lambda) = M/EI_L r$$

where $\Delta\alpha$ is the angle enclosed by the planes of adjacent rings after bending and λ is the distance between rings. Calculating $(M/E)^2$ from above equation and setting it into equations $(35a)$ and $(36a)$ we get

$$(c/r) = (1/12\,\pi)\,r^2\,(I_L/I_r)\,(\Delta\alpha/\lambda)^2 \quad . \quad . \quad . \quad (35b)$$

and

$$(d/r) = (\tfrac{3}{16}\,\pi^5)\,r^2\,(\lambda/r)^4\,(I_L/I_{str})\,(\Delta\alpha/\lambda)^2 \quad . \quad . \quad . \quad (36b)$$

The maximum possible values of the relative deflections (c/r) and (d/r) may be calculated on the ground of following considerations.

In case of small deflections the maximum strain in a bent cylinder may approximately be put (v. Fig. 9)

$$e_{max} = (d\Delta\alpha/dx)\,r = (\Delta\alpha/\lambda)\,r.$$

With the aid of Hooke's law we get

$$(\Delta\alpha/\lambda) = e_{max}/r = (p_{max}/E)\,(1/r)$$

where p_{max} is the greatest stress developed in the cylinder. Substituting above value into equations $(35b)$ and $(36b)$ we get

$$(c/r)_{max} = (1/12\,\pi)\,(I_L/I_r)\,(p_{max}/E)^2 \quad . \quad . \quad . \quad (35c)$$

and

$$(d/r)_{max} = (\tfrac{3}{16}/\pi^5)\,(\lambda/r)^4\,(I_L/I_{str})\,(p_{max}/E)^2 \quad . \quad . \quad . \quad (36b)$$

From above equations the maximum relative deflections of the rings and the stringers of any cylindrical monocoque structure can be calculated, if the greatest stress that can be sustained by the stringers is known. Since in very efficient monocoque structures made of duralumin the failing stress of the stringers will hardly exceed 30,000 lb. p. sq. in. (2,100 kg. p. sq. cm.) we get with $E = 10^7$ lb. p. sq. in. (700,000 kg. p. sq. cm.).[28]

$$(c/r)_{max} = 0.24 \times 10^{-6} \, (\bar{I}_L/\bar{I}_r) \quad . \quad . \quad . \quad . \quad (35d)$$

and

$$(d/r)_{max} = 0.55 \times 10^{-8} \, (\lambda/r)^4 \, (\bar{I}_L/\bar{I}_{str}) \quad . \quad . \quad . \quad (36d)$$

where the definitions for $\bar{I}_r$, $\bar{I}_{str}$ and $\bar{I}_L$ have been given in §§7, 8 and 9.

Since in case of fuselages neither the value of $(\bar{I}_L/\bar{I}_r)$, nor that of $(\lambda/r)^4 \, (\bar{I}_L/\bar{I}_{str})$ is likely to surpass 10^5, the maximum possible relative deflections are

$$(c/r)_{max} \leq 2.4 \text{ per cent.} \quad . \quad . \quad . \quad . \quad (35e)$$

and

$$(d/r)_{max} \leq 0.055 \text{ per cent.} \quad . \quad . \quad . \quad (36e)$$

the values corresponding to practical monocoque fuselages being very much smaller.

§11. Instability.

Since in case of normal fuselages the deflections of the stringers are, as shown in the preceding paragraph, much smaller than the flattening of the rings, (d/r) may be put equal zero in the following calculations. This means that the behaviour of the structure under bending moments will not materially differ from a monocoque cylinder, having continuously distributed rings or having perfectly rigid stringers. In this case the flattening and consequently the curvature being uniform throughout we may put

$$M = EI \, (d\Delta\alpha/dx) = EI \, (\Delta\alpha/\lambda).$$

With the aid of equation (31) we get

$$M = Er\bar{I}_L \, (\Delta\alpha/\lambda) \, [1 - (3/2) \, (c/r)] \quad . \quad . \quad . \quad (37)$$

Substituting this expression into equation (35) and neglecting terms with higher powers than the first of (c/r) we get after several transformations

$$9\pi\bar{I}_r \, (c/r) = r^2\bar{I}_L \, (\Delta\alpha/\lambda)^2 \, [(\tfrac{3}{4}) - (\tfrac{3}{8}) \, (c/r)] \quad . \quad . \quad . \quad (38)$$

With similar assumptions as made in the preceding paragraph the flattening ratio becomes

$$(c/r) = (1/12\,\pi) \, r^2 \, (\bar{I}_L/\bar{I}_r) \, (\Delta\alpha/\lambda)^2 \quad . \quad . \quad . \quad (38a)$$

Putting this expression in equation (37) we get

$$M = Er\bar{I}_L \, (\Delta\alpha/\lambda) \, [1 - (\tfrac{1}{8}\,\pi) \, r^2 \, (\bar{I}_L/\bar{I}_r) \, (\Delta\alpha/\lambda)^2] \quad . \quad . \quad (39)$$

St. Venant's solution may be found from above equation by omission of the second term in the brackets. As it may be seen from Fig. 10 the moment according to equation (39) is always smaller than given by St. Venant and reaches a maximum when

$$\partial M/\partial \, (\Delta\alpha/\lambda) = 0.$$

Differentiating equation (39) with respect to $(\Delta\alpha/\lambda)$ and putting the differential coefficient equal zero we get for the critical value of the curvature following equation

$$(\Delta\alpha/\lambda)^2_{cr} = (8/3\,\pi) \, (1/r^2) \, (\bar{I}_r/\bar{I}_L) \quad . \quad . \quad . \quad (40)$$

Substituting above expression into equation (38a) we get

$$(c/r)_{cr} = (2/9) = 22.2 \text{ per cent.} \quad . \quad . \quad . \quad . \quad (41)$$

The same expression was given for the critical value of the flattening ratio of thin-walled tubes by Brazier who was the first to demonstrate that at this

[28] Cf. Ref. 6 and Ref 12.

point a certain type of instability occurs, since after the applied moments have reached the value corresponding to the critical flattening ratio the flattening increases also in case the loads are not further increased.

It should, however, be mentioned, that the value 2/9 cannot be regarded as infinitely small and the higher powers of it must not be neglected. When considering the term with (c/r) in the brackets of equation (38), we get the following expression instead of equation (38*a*)

$$(c/r) = (1/12\,\pi)\, r^2\, (\bar{I}_L/\bar{I}_T)\, (\Delta\alpha/\lambda)^2 \,/\, [1 + (5/6)\, (1/12\,\pi)\, r^2\, (\bar{I}_L/\bar{I}_T)\, (\Delta\alpha/\lambda)^2] \qquad (42)$$

With the aid of above expression we get instead of equation (39)

$$M = E r \bar{I}_L\, (\Delta\alpha/\lambda)\, \{\, 1 - [(\tfrac{1}{8}\,\pi)\, r^2\, (\bar{I}_L/\bar{I}_T)\, (\Delta\alpha/\lambda)^2] \,/\, [1 + (5/72\,\pi)\, r^2\, (\bar{I}_L/\bar{I}_T)\, (\Delta\alpha/\lambda)^2] \,\} \quad . \quad . \quad . \quad . \qquad (43)$$

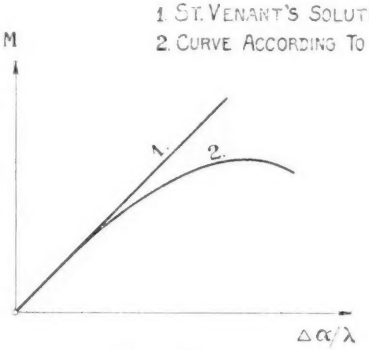

FIG. 10.

Proceeding in a similar way as above we get

$$(\Delta\alpha/\lambda)^2_{cr} = 12.44\, (1/r^2)\, (\bar{I}_T/\bar{I}_L) \quad . \quad . \quad . \quad . \qquad (44)$$

and consequently

$$(c/r)_{cr} = 0.259 = 25.9 \text{ per cent.} \quad . \quad . \quad . \quad . \qquad (45)$$

Neither this approximation can, however, be regarded as a very close one and it is even not quite certain that it is nearer to reality than the first result obtained. Namely, neglection of (c/r) against unity causes a deviation of the same magnitude as neglection of the second power of (c/r) against its first power. The second power of (c/r) has been, however, disregarded in all calculations, *e.g.*, when determining the radius of curvature of the rings, and the expression for the strain energy stored in the rings does not contain terms independent of (c/r). Since, however, in the preceding paragraph it has been calculated that at collapse the greatest deflection of practical fuselages does not exceed 1-2 per cent., the differences between deflections obtainable in reality and required for instability by theory are so large that it can be stated with confidence that in case of normal monocoque fuselage structures instability through flattening cannot occur.

§12. The Thin-Walled Tube.

It is of interest to apply the results obtained to the case of a thin-walled non-reinforced tube which may be regarded as the limiting case of a structure built of an infinite number of very closely spaced rings and stringers. Denoting the radius of the tube by r and the wall thickness by t we get

$$\bar{I}_L = r^2 t \pi$$
$$\bar{I}_T = (1/12)\, t^3$$
$$\bar{I}_L/\bar{I}_T = 12\,\pi\, (r/t)^2 \quad . \quad . \quad . \quad . \quad . \qquad (46)$$

Substituting this value into equation (39) we get

$$M = E\tau I_L (\Delta\alpha/\lambda) [1 - (3/2) r^2 (r/t)^2 (\Delta\alpha/\lambda)^2] \quad . \quad . \quad (47)$$

This equation is identical with equation (17) in Brazier's paper except the factor $(1-\sigma^2)$ which is missing in the present formula, since in consequence of the independent structural elements in longitudinal and transverse directions no interaction between longitudinal and tangential stresses has been assumed.

With the aid of equation (46) equation (40) becomes

$$(\Delta\alpha/\lambda)^2_{cr} = (2/9) (1/r^2) (t/r)^2$$

and the critical value of the flattening ratio remains unaltered

$$(c/r)_{cr} = (2/9).$$

In case of small deflections we can make use of equation (35c) and get after substitution of equation (46)

$$(c/r)_{max} = (r/t)^2 (p_{max}/E)^2 \quad . \quad . \quad . \quad . \quad (48)$$

When collapse is caused by flattening the value of c/r is 2/9 at failure. When, however, the tube buckles into the multi-lobed form, as observed by Brazier and others, before instability by flattening could have occurred, the maximum flattening ratio must be calculated in accordance with the buckling stress of the cylinder. This stress has already been quoted in §4, equation (14), for the case of compressed cylinders. It can be re-written in a more general form, viz.:—

$$p_{cr}/E = k (t/r) \quad . \quad . \quad . \quad . \quad . \quad (49)$$

where k is 0.6 according to theory. With this value we get instead of equations (41) or (45)

$$(c/r)_{max} = 0.36.$$

If the practical value of k should not be smaller than the above quoted theoretical value, the tube would fail by flattening. In experimental investigations of tubes in compression,[29] however, the constant k has been found much smaller, viz., 20 to 60 per cent. of the theoretical value which discrepancy is probably due to initial imperfections in the cylindrical form. For the critical stress of bent cylinders Lundquist[30] found that the multi-lobed form of instability observed on the whole circumference of compressed cylinders occurred also at the compression side of bent cylinders, but at a stress which was 30-80 per cent. higher than measured in case of compressed cylinders. The influence of k on the maximum flattening ratio may be seen from the following table:—

k ... =	0.6	0.4	0.3	0.2
$(c/r)_{max}$ =	0.36	0.16	0.09	0.04

These values are much greater than the maximum flattening ratio of monocoque structures and can, therefore, much easier be observed in experiments.

§13. Stress in Rings Due to Flattening.

The stresses due to distortions of the rings may be calculated with the aid of equation (20)

$$M = EI_r\lambda [(1/\rho) - (1/r)] \quad . \quad . \quad . \quad . \quad (20)$$

Denoting the moment of inertia of the ring by I_r

$$I_r = I_r\lambda$$

and making use of equation (23) we get

$$M_r = EI_r 3 (1/r) (c/r) \cos (2\phi).$$

The maximum moment occurs when $\phi = 0$, $\pi/2$, π and $3\pi/2$:—

$$M_{r\,max} = EI_r 3 (1/r) (c/r)$$

with

$$p_{r\,max} = M_{r\,max} (h/I_r)$$

[29] V. p. 462 of Ref. 22.
[30] V. Ref. 15. Cf. also p. 466 of Ref. 22.

where h is the greatest distance of any point of the ring section from its neutral axis, we get

$$p_{r\,max} = 3\,(h/r)\,(c/r)\,E \quad . \quad . \quad . \quad . \quad . \quad (50)$$

Setting $(c/r)_{max} = 0.01$ we get

$$p_{r\,max} = 0.03\,(h/r)\,E.$$

Such high value of (c/r) is necessarily only possible in case of weak rings when (h/r) is not likely to exceed 1/20. The maximum stress in the ring, therefore, becomes

$$p_{r\,max} = 0.0015\,E = 15{,}000 \text{ lb. p. sq. in.} = 1{,}050 \text{ kg. p. sq. cm.} \quad (50a)$$

which is a fairly high value in case of a ring made of duralumin. In special cases it can, therefore, be advisable to check ring stresses with the aid of equation (50).

§14. Rigid End Rings.

In case several weak rings are arranged between two stiffer ones, it is convenient to assume the latter to be perfectly rigid. Denoting the distance between both indeformable end rings by λ and supposing that the form of the deflections of stringers, the weak intermediate rings and the sheet covering is similar to that described in §6 and shown in Fig. 5, the calculation of the strain energy stored in the structure and the determination of the deflections can easily be carried out with the aid of the results of the previous paragraphs.

The differential coefficients of the strain energies with respect to the deflection ratio (c/r), where in this case (c/r) denotes the deflection ratio in the middle of the distance between end rings, are the following :—

Rings :—

$$\partial W_r/\partial\,(c/r) = 9\,\pi E\,(N/m)\,I_r\,(\lambda/r)\,(c/r)$$

where N is dependent on the number m of rings within λ. The factor N is dealt with in detail in §18 and values corresponding to different numbers of rings have been collected there in a table.

Stringers :—

$$\partial W_{str}/\partial\,(c/r) = 2\,\pi^5 E I_{str}\,(r/\lambda)^3\,(c/r).$$

Longitudinal stresses :—

$$\partial W_L/\partial\,(c/r) = -\,(1/2)\,(\lambda/r)\,(M^2/EI_L)\,[(3/4) + (39/32)\,(c/r)].$$

Equating the sum of above three differential coefficients to zero we get for the flattening ratio after neglecting the term $(39/32)\,(c/r)$ against $(3/4)$:—

$$(c/r) = (1/\psi)\,(M/E)^2 \quad . \quad . \quad . \quad . \quad (51)$$

where

$$\psi = 8\,\pi I_L\,[3\,(N/m)\,I_r + (2/3)\,\pi^4\,(r/\lambda)^4\,I_{str}] \quad . \quad . \quad . \quad (51a)$$

In the table below values of (N/m) and (m/N) have been collected for different numbers m of weak rings between both rigid ones :—

m =	1	2	3	4	5
m/N =	1.0	1.78	2.0	2.13	2.22
N/m =	1.0	0.562	0.50	0.469	0.45

For comparison of above expression with equation (35a) the stringers will be assumed very very weak ($I_{str} = 0$), when

$$(c/r) = (1/24\,\pi)\,(m/N)\,(1/I_L I_r)\,(M/E)^2 \quad . \quad . \quad . \quad (52)$$

With the aid of above table it may be found that in this case the calculation of the deflections according to equations (35a) and (52), respectively, gives nearly the same results. Since, however, the second term in the brackets mostly outweighs the first one, the deflections between rigid end rings will turn out even smaller than those calculated in §10.

§15. The Effect of Neglections

In addition to the effect of the arbitrarily chosen form for deflections which, as outlined in §6, cannot influence materially the results obtained, there are some other points in the previous calculations which need be considered in some detail.

Deductions made in the previous paragraphs were based on the assumptions that the sheet covering of the monocoque structure was thin enough to be neglected against the rings and the stringers when calculating the strain energy stored in the system, but thick enough to remain under loads in the unbuckled state. In fact in most fuselages the sheet buckles long before collapse of the structure occurs, yet in the buckled state it carries a fairly high proportion of the load and cannot, consequently, be neglected.

The most important effect of the sheet covering concerns the distorted form of the structure. As long as the stringers may be regarded infinitely stiff ($(d/r)=0$), the sheet influences only the moments of inertia of the sections of the cylinder and of the rings. If, however, the rate of flattening varies with the longitudinal co-ordinate of the cylinder, the assumptions made for distortions involve shearing strains between the fibres of the sheet covering. This means that only the deformations of the stringers and rings are inextensional, but in the sheet shearing stresses appear. As long as the sheet is very thin, the work stored in it cannot be large and may not materially influence the results obtained in the previous paragraphs, even if the shearing stresses attain considerable values. In case of less thin sheet, however, the share of the sheet in the deformation work can cause the rings and stringers to distort in a form which is different from our assumptions and is not more inextensional. In such case the rate of flattening calculated above must be greater than in reality, since a considerable part of the strain energy stored in the structure has been neglected.

These considerations turn out differently after the panels buckled. Since the distance between stringers is smaller than the length of the arc of the curved sheet, some greater movability must result from the buckling of the panels, with the effect that the strain energy required for the deformation of the sheet decreases and consequently our results do not deviate as much from reality as in case of unbuckled panels. On the other hand, after buckling, the assumptions for the tangential deformations of the stringers hold only true at intersection points with rings and the stringers need not distort tangentially between rings. This circumstance can be allowed for by replacing equation (26a) by the following formula :—

$$\bar{I}_{str}=\bar{I}_{str\cdot r}+k\bar{I}_{str\cdot t} \quad . \quad . \quad . \quad . \quad . \quad (53)$$

where

$$k\leq(\tfrac{1}{4}) \quad . \quad . \quad . \quad . \quad . \quad . \quad (53a)$$

Since further in case of the calculation of the flattening, one part of the sheet is working in the unbuckled, another in the buckled state, it is extremely difficult to consider simultaneously all these circumstances. It was, therefore, considered advisable to retain our assumptions regarding distortions. From all above considerations it follows that the results obtained in the preceding calculations should well apply to monocoque cylinders having closely spaced stringers and rings and covered by very thin sheet; this represents a promising form of monocoque design.[31] If, however, stringers and rings are spaced farther apart and the structure is covered by sheets not so thin, then the above neglections cause a greater deviation from fact. The latter holds true for another promising form of monocoque construction, viz., when corrugated sheet covered by smooth sheet[32] is used instead of the more general combination of stringers and smooth sheet covering. In all these cases, however, the approximation obtained is sufficiently good if we do not forget that the aim of the calculations of Part II was

[31] V. Ref. 6.
[32] V. Ref. 12.

not to deduce exact formulæ for the deformations, but to provide some informative data regarding the rate of flattening of monocoque structures and to prove that instability by flattening cannot occur.

Further effects of the sheet covering can be allowed for as follows:—

Until the buckling stress of the sheet is reached, the moment of inertia of the sheet can simply be added to the moment of inertia of the stringers when calculating the longitudinal stresses in the structure.

The effect of the sheet covering on the bending stiffness of the stringers cannot, however, be so easily determined. A solution for a similar problem has been given by Metzer[33] who, with the aid of a method evolved by Professor von Kármán, calculated the effective width of thin unbuckled plates for several cases of practical interest. In the present case the bending moment acting on the combination of a stringer and the effective width may approximately be put

$$M = k \cos (2 \pi x/\lambda) \quad . \quad . \quad . \quad . \quad . \quad (54)$$

since the curvature of a stringer was given in a similar form in §8.[34]

The results of Metzer's calculations regarding such a moment distribution have been replotted in Fig. 11, where $2w$ is the effective width of sheet which

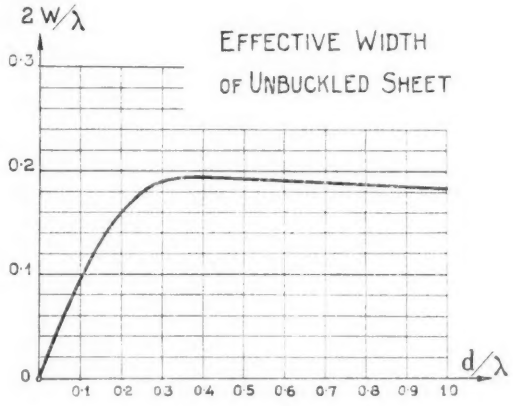

FIG. 11.

should be added to the stringer section when calculating its moment of inertia, d the distance between stringers and λ the wave-length.

Since, however, equation (54) represents only a rough approximation and since, further, Metzer's results apply to flat sheet and to the case when axial stresses are not acting, Fig. 11 should be used for informative purposes only.

The moment distribution over the rings being similar to that over the stringers, Fig. 11 should also apply to this case. Since, however, the curved fibres of the sheet can neither resist compression, nor tension, without buckling or flattening, respectively, the effective width must be very much smaller.

After the sheet covering has buckled, its load carrying capacity decreases gradually. This decrement may be, however, easily allowed for by calculating the moment of inertia of the structure taking each stringer section and the respective effective width of sheet, as outlined in Part I, and not the stringer sections and the whole sheet.

For calculating the resistance of the stringers against buckling, the share of

[33] V. Ref. 17.

[34] φ is a constant for a stringer.

the sheet may be accounted for by making use of the reduced effective width, as outlined in Part I.

In the case of rings, however, no reliable data are available.

The second neglection to be considered here is the effect of the assumption that the number of stringers is sufficiently large to be considered as continuously distributed over the circumference of the cylinder. In fact, in most fuselages there are so numerous stringers that above assumption does not restrict the applicability of results obtained. The simplification obtained thereby consists in getting integrals instead of sums. In the following, however, it will be shown that in special cases of symmetrical distribution of even a small number of stringers the results of the summations are identical with the integrals calculated in the foregoing paragraphs. The demonstration will be restricted to the case of very rigid stringers supported by narrow-spaced rings, $(d/r)=0$.

In consequence of the finite number of stringers the shear transmitted to the rings must be discontinuous over the circumference. Since, according to ordinary beam theory, the shear in a bent beam is proportional to the third derivative of the deflections with respect to the longitudinal co-ordinate of the beam, the third derivative of the expression for the deflections must be discontinuous too. This requirement contradicts equations (16) and (17) which have continuous derivatives of any order.

Though above considerations prove that equations (16) and (17) are not strictly valid in case of a finite number of stringers, they may be regarded as good approximations to the real distortions of rings, unless the number of stringers is extremely small. The following calculations will, therefore, again be carried out on the ground of the assumptions used so far.

Equations (16) and (17) remaining unaltered, the strain energy stored in the rings necessarily retains its value calculated in §7. The strain energy due to bending of the stringers vanishes in consequence of the assumption made $(d/r)=0$. The only term to be recalculated is, therefore, the strain energy due to longitudinal stresses which has been given in equation (28) in the form:—

$$W_L=(\tfrac{1}{2})\,E\int\sin^2\phi\,(r-\bar{c}\,\sin^2\phi)^2\,(d\Delta\alpha/dx)^2\,dV \quad . \quad . \quad (28)$$

In consequence of the present assumptions $(d\Delta\alpha/dx)$ may be replaced by $(\Delta\alpha/\lambda)$ and $\bar{c}$ by c. By these substitutions we get after integration

$$W_L=(\tfrac{1}{2})\,EI_L\lambda\,(\Delta\alpha/\lambda)^2\,[1-(3/2)\,(c/r)+(\tfrac{5}{8})\,(c/r)^2] \quad . \quad (55)$$

where

$$I_L=\pi r^3 t \quad . \quad . \quad . \quad . \quad . \quad . \quad (55a)$$

Equation (55) represents the strain energy due to longitudinal stresses stored in a structure having continuously distributed stringers which are rigid against bending. In case of a finite number of stringers the strain energy may be computed in the following way:—

The final distance of a stringer from the centroidal axis is after deformation (v. equation (27))

$$v+w_v=\sin\phi\,(r-c\,\sin^2\phi).$$

The strain in the stringer is

$$e=\sin\phi\,(r-c\,\sin^2\phi)\,(\Delta\alpha/\lambda).$$

The strain energy in one stringer is therefore

$$W_L=(\tfrac{1}{2})\,E\,\sin^2\phi\,(r-c\,\sin^2\phi)^2\,(\Delta\alpha/\lambda)^2\,A\lambda$$

where A is the sectional area and λ the length of the stringer.

The strain energy stored in the whole structure is consequently

$$\Sigma W_L=(\tfrac{1}{2})\,Er^2\lambda\,(\Delta\alpha/\lambda)^2\,\{\,\Sigma A\,\sin^2\phi-2\,(c/r)\,\Sigma A\,\sin^4\phi+(c/r)^2\,\Sigma A\,\sin^6\phi\,\} \quad (56)$$

Since in this case

$$I_L=r^2\Sigma A\,\sin^2\phi \quad . \quad . \quad . \quad . \quad . \quad (56a)$$

the conditions that equations (55) and (56) become identical are

$$\Sigma A \sin^4 \phi = (\tfrac{3}{4}) \Sigma A \sin^2 \phi \quad . \quad . \quad . \quad . \quad (57a)$$

and

$$\Sigma A \sin^6 \phi = (\tfrac{5}{8}) \Sigma A \sin^2 \phi \quad . \quad . \quad . \quad . \quad (57b)$$

where the summation has to be extended over all stringers.

Conditions (57*a*) and (57*b*) are fulfilled by a great many symmetrical arrangements of stringers, *e.g.*, by 8, 12, or 24 evenly spaced stringers of equal sectional area, when they are placed at the angles

$$\phi_n = n\ (\pi/4),\ n\ (\pi/6) \text{ or } n\ (\pi/12),$$

respectively, where $n = 0, 1, 2$, etc., and ϕ has to be measured as shown in Fig. 6.

It may be mentioned further that the strain energy due to bending of the rings out of their plane has also been neglected. In the case when (d/r) vanishes, the rings naturally remain plane, in the case, however, when (d/r) has some finite value, only one ring can remain plane and all the rest must distort perpendicularly to their plane in consequence of the non-uniform extensions of the stringers. It may, however, easily be demonstrated that the longitudinal displacements of the intersection points of the rings with stringers in consequence of the shortening of the stringers due to deflections are proportional to $(d/r)^2$. Since in all previous calculations (d/r) has been considered infinitely small, $(d/r)^2$ is small of the second order and may be neglected against the deflections of the rings and stringers. The same can, of course, be said of the strain energy due to these deformations. In addition, in most fuselages the stiffness of the ring sections against bending out of their plane is small.

At last some remarks may be added on cylindrical monocoque structures of non-circular cross section.

The critical flattening ratio and the corresponding stress of orthogonally anisotropic cylinders of elliptic cross section have been calculated by O. S. Heck.[35] From this very complex analytical treatment follows that at failure the shortening of one axis of the elliptic section divided by its length remains invariably (2/9), while the elongation of the other axis divided by its length turns out smaller if the bending moment is acting in the plane of the minor axis and larger, if acting in the plane of the major axis. The critical value of the bending moment is in the former case larger and in the latter case smaller than for a circular cylinder of a radius equal to the radius of curvature of the elliptic section at that point, where the stress in the cylinder is a maximum. In practical cases, however, the greatest possible deviation is about 20 per cent. only. In the experiments carried out by Heck the cylinders collapsed approximately at the stresses predicted by theory. Failure, however, occurred by the formation of several lobes, similarly to the tests of Brazier and Lundquist.

On the ground of Heck's investigations it can, therefore, be stated that the behaviour of elliptic cylinders is not much different from circular cylinders. Consequently the general conclusions of the preceding paragraphs concerning maximum flattening ratio and possibility of failure by flattening can also be applied to cylinders of elliptic cross section.

Part III.

Local Buckling of Monocoque Structures.

§16. Introduction.

In case of normal monocoque aeroplane fuselages relatively strong rings are spaced at distances equal to ½-1 diameter of the fuselage, failure of the structure always occurs by instability of the most stressed stringer. The buckling stress, however, is mostly very low, especially, when the number of stringers is great and consequently the cross section of one stringer is small. The value of the

[35] V. Ref. 7.

stress at failure may be raised by spacing the rings nearer and reducing thereby the free length and, consequently, the slenderness ratio of the stringers. In this case the rings should be constructed of lighter sections in order to balance the increment of weight of the whole structure due to the greater number of rings.

By decreasing gradually the interval between rings a critical distance is reached when the most stressed stringer does not buckle between adjacent rings, but forces one or more supporting rings to deform simultaneously. This form of instability will in the following be termed local buckling of the monocoque structure.

The phenomenon is similar to the instability of a column on elastic intermediate supports. In case of Fig. 12 all three buckled forms shown are possible and it

COLUMN ON ELASTIC INTERMEDIATE SUPPORTS.

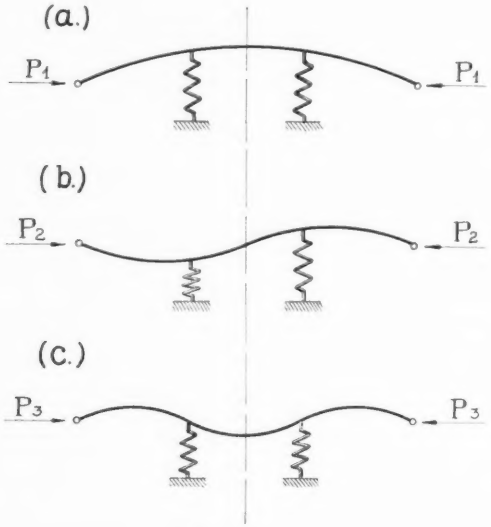

FIG. 12.

depends upon the elastic resistance of the supports (*i.e.*, upon the value of the spring constants) and upon the stiffness of the strut as to which form corresponds to the least value of the critical load, *i.e.*, which form of instability occurs first, if no other external constraint is present.

In monocoque structures the deformation of the rings involves, in addition to the deformation of the most stressed stringer, distortions of several neighbouring less stressed stringers too, which, therefore, have also some influence upon the value of the critical load, thus rendering the problem more complex. The method used for calculating the critical load may be summarised as follows:—

A probable shape of the cylinder after buckling, involving distortions of several rings and several stringers, has been assumed. A strict accordance of the assumed shape to the true shape after buckling is not essential, since the calculations have been carried out with the aid of strain energy methods. It has been assumed that no other deformations of the structure than those corresponding to ordinary bending theory occur until the critical value of the bending moment acting upon the structure is attained. After this value is reached the monocoque cylinder buckles without any further increase of the external moment.

According to these assumptions the strain energy due to bending, stored in the rings and stringers corresponding to the assumed shape after buckling of the monocoque structure, must equal the work done by the stresses in the end sections of the monocoque structure during displacements of their points of attack corresponding to the assumed deformations after buckling. From this condition the value of the critical load can be calculated.

For greater accuracy two parameters have been incorporated in the assumptions for the deformed shape. By varying the parameters the minimum of all those values of the critical load can be found which are consistent with the assumptions.

Since in most fuselages the stringers are spaced closely and since the following calculations show that the deformations of the rings extend to a fairly large portion of the circumference, it has been assumed that the stringers are distributed continuously.

A similar assumption for the rings is not advisable, since at failure mostly a small number of rings are only involved. This is a consequence of the fact that in practice neither the bending moment nor the stresses are constant for any greater length of the fuselage.

It must be mentioned that again in all calculations the sheet covering's share in strain has been neglected. Results hold true, therefore, for very (infinitely) thin sheet only. Part of the effect of the sheet covering may, however, be approximated by calculating areas and moments of inertia of stringers and rings for the combinations of section plus effective width of sheet, in similar way as already outlined in § 15.

§17. The Distorted Shape of the Cylinder at Failure.

In consequence of the effect of the sheet covering the most stressed stringer is not likely to buckle in the outward direction. It has been assumed, therefore, that the deflection of any point of this stringer may be given with sufficient accuracy by the equation

$$y = a\,[1 - \cos(2\pi x / L)] \quad . \quad . \quad . \quad . \quad (58)$$

DISTORTION OF STRINGERS.

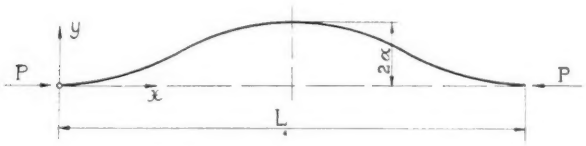

FIG. 13.

The designation of the symbols may be understood from Fig. 13. The greatest radial deflection in the inward direction is $2a$, the smallest deflection is zero. Every ring within the wave length L must also become distorted in consequence of the deformation of the most stressed stringer and the deformations of the rings cause the adjacent stringers to become deflected too. It has been assumed that the deflected shape of all these stringers is given by equation (58) the constant coefficient differing only and being smaller than a.

The shape of the cylinder at any transverse section (v. Fig. 14) must fulfil the following conditions:—

(1) Maximum radial deflection must occur when $\phi = 0$.

(2) For reasons of symmetry the tangential displacement must vanish for $\phi = 0$.

(3) The radial displacement must vanish for $\phi = \phi_0$.
(4) The tangential displacement must vanish for $\phi = \phi_0$.
(5) The tangent to the deflected shape must be perpendicular to the original radius of the cylinder for $\phi = \phi_0$.
(6) The radius of curvature of the deflected shape must equal the original radius of the cylinder for $\phi = \phi_0$.
(7) Deformations must be inextensional (*Cf.* §7).

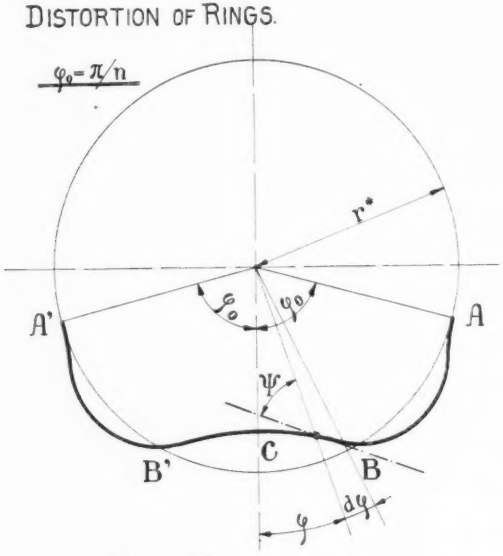

FIG. 14.

With notations used in §7 condition (7) may be written (v. equation (15))

$$w_r = -dw_t/d\phi \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Denoting the angle between the tangent and the radius by ψ (v. Fig. 14), $\cot\psi$ is given by

$$\cot\psi = (1/r)\,(dr/d\phi)$$

with

$$r = r^* + w_r$$

where r^* is the original radius of the cylinder we get

$$\cot\psi = [1/(r^* + w_r)]\,(dw_r/d\phi).$$

Condition (5), therefore, reduces to

$$\cot\psi = 0$$

or, since r^* has a finite constant value and w_r is very small,

$$dw_r/d\phi = -d^2w_t/d\phi^2 = 0$$

when $\phi = \phi_0$.

Since according to equation (22) the radius of curvature of the deformed shape is given by

$$(1/\rho) = (1/r^2)\,[r - w_r - (d^2w_r/d\phi^2)] \quad . \quad . \quad . \quad (22)$$

condition (6) may be written in the form

$$w_r + d^2w_r/d\phi^2 = 0.$$

The above seven conditions may, therefore, be transformed into the following six conditions:—

$$\left.\begin{array}{l}(1)\ d^2w_t/d\phi^2=0 \text{ when } \phi=0\\(2)\ w_t=0 \text{ when } \phi=0\\(3)\ dw_t/d\phi=0 \text{ when } \phi=\phi_0\\(4)\ w_t=0 \text{ when } \phi=\phi_0\\(5)\ d^2w_t/d\phi^2=0 \text{ when } \phi=\phi_0\\(6)\ dw_t/d\phi+d^3w_t/d\phi^3=0 \text{ when } \phi=\phi_0\end{array}\right\} \quad . \quad . \quad . \quad (59)$$

Since for very small deflections any inwardly deflected line between two points of the original circumference B, B', if of reasonably simple form, is shorter than the original arc of the circle, the portion of the ring beyond the two points must bulge out, if there the deformations are also inextensional.

The assumption for the deformed shape of the rings used in the following calculations is, therefore,

$$w_r=-\beta\left[\cos(n\phi)+\cos(2n\phi)\right] \quad . \quad . \quad . \quad (60)$$

From the condition of inextensional deformations we get

$$w_t=\beta\left[(1/n)\sin(n\phi)+(1/2n)\sin(2n\phi)\right] \quad . \quad . \quad . \quad (61)$$

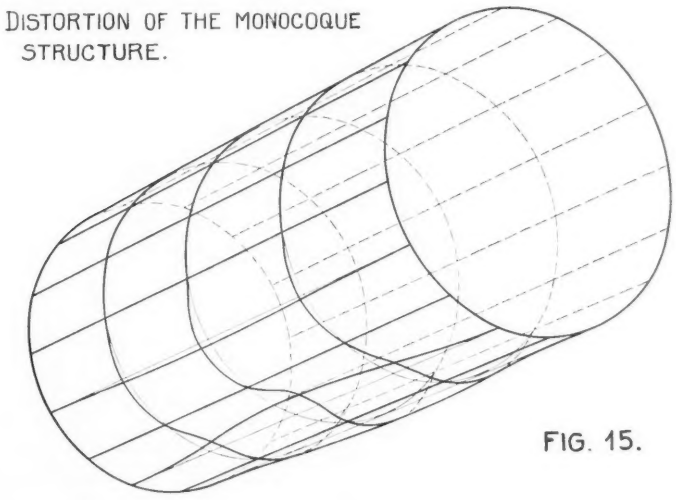

FIG. 15.

The first five conditions are fulfilled by above assumption, as it may be easily verified ($\phi_0=(\pi/n)$). The sixth condition, however, is not fulfilled. Consequently, according to the assumed form of distortions, deflections and tangents are continuous throughout, but the curvature shows discontinuities at points A and A'. This would be possible, if at points A and A' concentrated bending moments were acting, what has not been assumed. The consequences of this inexactitude of the assumptions are, however, immaterial.

In cylindrical-polar co-ordinates the form of the entire wave is, therefore, given by the following equations:—

$$w_r=-(a/2)\left[1-\cos(2\pi x/L)\right]\left[\cos(n\phi)+\cos(2n\phi)\right] \quad . \quad . \quad (62)$$

$$w_t=(a/2)\left[1-\cos(2\pi x/L)\right]\left[(1/n)\sin(n\phi)+(1/2n)\sin(2n\phi)\right] \quad . \quad (63)$$

This form is shown in Fig. 15.

The strain energy stored in the rings due to bending would turn out smaller if the bulges between B, A and B', A' would extend to a greater part of the

ring, or to the whole circumference of the ring. In this case all outwardly directed deflections would be smaller and the sum of the squares of the deflections —which appears in the expression for the strain energy—would be also smaller than according to the shape given by equations (62) and (63) and shown in Fig. 15. The real critical value of the bending moment should, therefore, be slightly smaller than calculated on the basis of the above assumptions.

§18. Calculation of the Critical Load.

(a) *Strain Energy Stored in the Rings.*

With the assumption

$$w_r = -\beta\,[\cos(n\phi) + \cos(2\,n\phi)] \quad . \quad . \quad . \quad (60)$$

we get for the curvature according to equation (22)

$$(1/\rho) = (1/r)\,\{\,1 - (\beta/r)\,[(n^2-1)\cos(n\phi) + (4\,n^2-1)\cos(2\,n\phi)]\,\}\,.$$

The strain energy W_r stored in one ring is (*cf.* §7, equation (21))

$$W_r = (\tfrac{1}{2})\,E_r I_r \int [(1/\rho) - (1/r)]^2\, r\,d\phi.$$

Hence

$$W_r = (\tfrac{1}{2})\,(1/r)\,(\beta/r)^2\,EI_r \int_{-\pi/n}^{\pi/n} [J_1 + J_2 + J_3]\,d\phi$$

where

$$\int_0^{\pi/n} J_1\,d\phi = (n^2-1)^2 \int_0^{\pi/n} \cos^2(n\phi)\,d\phi = (\tfrac{1}{2})\,(n^2-1)^2\,(\pi/n)$$

$$\int_0^{\pi/n} J_2\,d\phi = 2\,(n^2-1)\,(4\,n^2-1) \int_0^{\pi/n} \cos(n\phi)\cos(2\,n\phi)\,d\phi = 0$$

$$\int_0^{\pi/n} J_3\,d\phi = (4\,n^2-1)^2 \int_0^{\pi/n} \cos^2(2\,n\phi)\,d\phi = (\tfrac{1}{2})\,(4\,n^2-1)^2\,(\pi/n).$$

Consequently we get

$$\int_{-\pi/n}^{+\pi/n} [J_1 + J_2 + J_3]\,d\phi = (\pi/n)\,[(n^2-1)^2 + (4\,n^2-1)^2]$$

whence

$$W_r = (\tfrac{1}{2})\,(\pi/n)\,[17\,n^4 - 10\,n^2 + 2]\,(1/r)\,(\beta/r)^2\,EI_r \quad . \quad . \quad (64)$$

In case there is only one ring within the wave length L (at the middle, v. Fig. 13), β may be replaced by a. If there are two evenly spaced rings, β may be put equal $0.75\,a$ and the strain energy stored in both rings becomes N times greater than in the first case with only one ring, when

$$N = 2 \times 0.75^2 = 1.125.$$

The strain energy stored in all rings within one wave length may, therefore, be written

$$W_{r\cdot tot} = (\pi/2)\,[17\,n^3 - 10\,n + (2/n)]\,(1/r)^3\,Na^2 E_r I_r \quad . \quad . \quad (65)$$

The values of N corresponding to different values of m, *i.e.*, number of rings within one wave length L, have been collected in the following table:—

m	1	2	3	4	5
N	1	1.125	1.5	1.878	2.25

(*b*) *Strain Energy Stored in the Stringers.*

According to the assumption made in § 17 the deflections of the most stressed stringer are given by equation (58):—

$$y = \alpha\,[1 - \cos\,(2\,\pi x/L)] \quad . \quad . \quad . \quad . \quad (58)$$

Denoting by $I_{str\cdot r}$ the moment of inertia of the cross section of the stringer against bending in the direction of the radius of the cylinder, the strain energy may be written

$$W = (\tfrac{1}{2})\,E_{str} I_{str\cdot r} \int_0^L (d^2y/dx^2)^2\,dx.$$

Hence

$$W = (\tfrac{1}{2})\,E_{str} I_{str\cdot r} \alpha^2\,(2\,\pi/L)^4 \int_0^L \cos^2\,(2\,\pi x/L)\,dx = 4\,\pi^4\,(E_{str} I_{str\cdot r}/L^3)\,\alpha^2.$$

Since the stringers may be regarded as continuously distributed over the circumference of the cylinder, the strain energy stored in all stringers may be computed in accordance with assumptions made in § 17 from the integral

$$W_{str\cdot r} = 4\,\pi^4\,(E_{str} I_{str\cdot r}/L^3 d)\,(\tfrac{1}{4})\,\alpha^2 \int_{-\pi/n}^{+\pi/n} [\cos\,(n\phi) + \cos\,(2\,n\phi)]^2\,r d\phi \quad . \quad (66)$$

where d denotes the distance between two adjacent stringers as measured over the circumference of the cylinder. (In this equation the factor $(\frac{1}{4})$ is necessary, since the maximum value of the term $[\cos\,(n\phi) + \cos\,(2\,n\phi)]$ equals 4 and not unity, when $\phi = 0$.)

Since

$$\int_{-\pi/n}^{+\pi/n} \cos^2\,(n\phi)\,d\phi = \int_{-\pi/n}^{+\pi/n} \cos^2\,(2\,n\phi)\,d\phi = \pi/n$$

and

$$\int_{-\pi/n}^{+\pi/n} \cos\,(n\phi)\,\cos\,(2\,n\phi)\,d\phi = 0.$$

Hence

$$W_{str\cdot r} = 2\,\pi^5\,(1/n)\,\alpha^2 r\,(E_{str}/L^3)\,(I_{str\cdot r}/d) \quad . \quad . \quad . \quad (67)$$

In accordance with the assumptions made for the distorted shape of the cylinder the most stressed stringer deflects only radially, but the other stringers also tangentially. Denoting by $I_{str\cdot t}$ the moment of inertia of the cross section of the stringer against bending in the direction of the tangent to the circumference of the cylinder, we get instead of equation (66) the following integral:—

$$W_{str\cdot t} = 4\,\pi^4\,(E I_{str\cdot t}/L^3 d)\,(\tfrac{1}{4})\,\alpha^2 \int_{-\pi/n}^{+\pi/n} [(1/n)\,\sin\,(n\phi) + (1/2\,n)\,\sin\,(2\,n\phi)]^2 r d\phi \quad (68)$$

Since

$$(1/n)^2 \int_{-\pi/n}^{+\pi/n} [\sin\,(n\phi) + (\tfrac{1}{2})\,\sin\,(2\,n\phi)]^2\,d\phi = (1/n)^2\,[(\pi/n) + (\tfrac{1}{4})\,(\pi/n)].$$

Hence

$$W_{str\cdot t} = (5/4)\,\pi^5\,(1/n)^3\,\alpha^2 r\,(E/L^3)\,(I_{str\cdot t}/d) \quad . \quad . \quad . \quad (69)$$

The total strain energy stored in the stringers due to bending may be written in the following form:—

$$W_{str\cdot tot} = 2\,\pi^5\,(1/n)\,\alpha^2\,(r/d)\,(E_{str} I_{str}/L^3) \quad . \quad . \quad . \quad (70)$$

where

$$I_{str} = I_{str\cdot r} + \left(\frac{s}{8}\right)(1/n^2)\, I_{str\cdot t} \quad . \quad . \quad . \quad . \quad (70a)$$

Since n cannot be smaller than unity and since in normal design $I_{str\cdot t}$ is smaller or much smaller than $I_{str\cdot r}$, in most cases $I_{str\cdot r}$ may be put for I_{str} with sufficient accuracy.

It may be mentioned that in the deductions of this section it was tacitly supposed that the principal axes of inertia of the cross section of the stringers were situated in the directions of the radius and the tangent to the circumference of the cylinder, respectively, which is the case in most of the actual fuselage constructions.

(*c*) *Work Done by the External Load.*

At the moment when buckling begins, the longitudinal stresses due to bending are distributed approximately according to a linear law. Consequently the longitudinal force acting on the infinitely small length $rd\phi$ of the circumference of the cylinder is

$$dP = (P/d)\cos\phi r d\phi \quad . \quad . \quad . \quad . \quad . \quad (71)$$

where P is the force acting on the most stressed stringer, d the distance between adjacent stringers and stringers are again considered distributed continuously over the circumference.

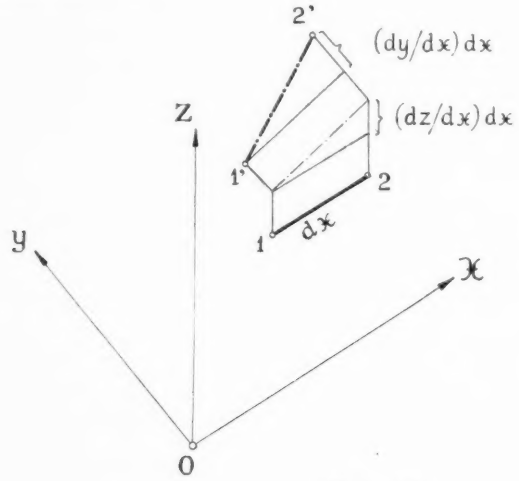

FIG. 16.

The displacements of the points of attack of the longitudinal forces are caused by the shortening of the distance between end points of the stringers due to radial and tangential deflections. This shortening may be calculated in the following way.

The difference between displacements in the direction of the axis y of the end points 1 and 2 of the infinitely short distance dx is (v.Fig. 16)

$$(dy/dx)\, dx.$$

The corresponding difference in the direction of the z-axis is

$$(dz/dx)\, dx.$$

The length $L + \Delta L$ of the distance $1' - 2'$ is therefore

$$L + \Delta L = \sqrt{[dx^2 + (dy/dx)^2\, dx^2 + (dz/dx)^2\, dx^2]}$$
$$= dx\sqrt{[1 + (dy/dx)^2 + (dz/dx)^2]} \quad . \quad . \quad . \quad (72)$$

If deflections are small (dy/dx) and (dz/dx) are also small and equation (72) may be written

$$L+\Delta L=dx\,[1+(\tfrac{1}{2})\,(dy/dx)^2+(\tfrac{1}{2})\,(dz/dx)^2].$$

The increment of length of the distance dx is consequently

$$\Delta L=dx\,[(\tfrac{1}{2})\,(dy/dx)^2+(\tfrac{1}{2})\,(dz/dx)^2] \quad . \quad . \quad . \quad (73)$$

When deformations are inextensional the length of the stringers after deformation equals the length before deformations and ΔL, as expressed in equation (73), is the amount by which the distance between end points has become smaller in consequence of the deflections. The shortening of the length L of the most stressed stringer due to radial deflections is therefore

$$\Delta L_{\max}=(\tfrac{1}{2})\int_0^L (dy/dx)^2\,dx=(\tfrac{1}{2})\,(2\,\pi/L)^2\,a^2\int_0^L \sin^2\,(2\,\pi x/L)\,dx=\pi^2\,(1/L)\,a^2. \quad (74)$$

The shortening at any other point of the circumference is

$$\Delta L=(\pi^2/L)\,(\tfrac{1}{4})\,a^2\,[\cos\,(n\phi)+\cos\,(2\,n\phi)]^2 \quad . \quad . \quad (74a)$$

Since according to the assumptions of § 16 the value of P remains constant during buckling, the work done by the external load at any point of the circumference is

$$dW_{\text{p·r}}=\pi^2\,(P/d)\,(r/L)\,(\tfrac{1}{4})\,a^2\cos\,\phi\,[\cos\,(n\phi)+\cos\,(2\,n\phi)]^2\,d\phi.$$

The total work done by the external load (*i.e.*, by the stresses at the end sections) during buckling in consequence of deflections in radial direction is given by

$$W_{\text{p·r}}=(\tfrac{1}{4})\,\pi^2\,(P/d)\,(r/L)\,a^2\int_{-\pi/n}^{+\pi/n}\cos\,\phi\,[\cos\,(n\phi)+\cos\,(2\,n\phi)]^2\,d\phi \quad . \quad (75)$$

After several transformations the expression to be integrated becomes

$$\cos\,\phi\,[\cos\,(n\phi)+\cos\,(2\,n\phi)]^2=\cos\,\phi+\cos\,\phi\,\cos\,(n\phi)$$
$$+(\tfrac{1}{2})\,\cos\,\phi\,\cos\,(2\,n\phi)+\cos\,\phi\,\cos\,(3\,n\phi)+(\tfrac{1}{2})\,\cos\,\phi\,\cos\,(4\,n\phi).$$

Integration of the terms of above sum gives:—

$$\int_0^{\pi/n}\cos\,\phi\,d\phi=\sin\,(\pi/n)$$

$$\int_0^{\pi/n}\cos\,\phi\,\cos\,(n\phi)\,d\phi=-(\tfrac{1}{2})\,\sin\,(\pi/n)\,[1/(1+n)+1/(1-n)]$$

$$\int_0^{\pi/n}\cos\,\phi\,\cos\,(2\,n\phi)\,d\phi=(\tfrac{1}{2})\,\sin\,(\pi/n)\,[1/(1+2\,n)+1/(1-2\,n)]$$

$$\int_0^{\pi/n}\cos\,\phi\,\cos\,(3\,n\phi)\,d\phi=-(\tfrac{1}{2})\,\sin\,(\pi/n)\,[1/(1+3\,n)+1/(1-3\,n)]$$

$$\int_0^{\pi/n}\cos\,\phi\,\cos\,(4\,n\phi)\,d\phi=(\tfrac{1}{2})\,\sin\,(\pi/n)\,[1/(1+4\,n)+1/(1-4\,n)].$$

The value of the whole integral extended from $-\pi/n$ to $+\pi/n$ is therefore

$$\int_{-\pi/n}^{+\pi/n}\cos\,\phi\,[\cos\,(n\phi)+\cos\,(2\,n\phi)]^2\,d\phi=2\,\sin\,(\pi/n)\,[1-1/(1-n^2)+\tfrac{1}{2}/(1-4\,n^2)$$
$$-1/(1-9\,n^2)+\tfrac{1}{2}/(1-16\,n^2)],$$

Consequently the total work done by the loads during buckling due to radial deflections is

$$W_{P\cdot r} = (\tfrac{1}{2})\,\pi^2\,(P/d)\,(r/L)\,\alpha^2 M_1 \quad . \quad . \quad . \quad . \quad (76)$$

where

$$M_1 = \sin(\pi/n)\,[1 - 1/(1-n^2) + \tfrac{1}{2}/(1-4n^2) - 1/(1-9n^2) + \tfrac{1}{2}/(1-16n^2)] \quad (76a)$$

The work done by the external loads in consequence of the shortening due to the tangential displacements is (similarly to equation (75)):—

$$W_{P\cdot t} = (\tfrac{1}{4})\pi^2\,(P/d)\,(r/L)\,\alpha^2 \int_{-\pi/n}^{+\pi/n} \cos\phi\,[(1/n)\sin(n\phi) + (1/2n)\sin(2n\phi)]^2\,d\phi \quad (77)$$

After several transformations the expression to be integrated becomes

$$\cos\phi\,[(1/n)\sin(n\phi) + (1/2n)\sin(2n\phi)]^2 = (1/n^2)\,[(\tfrac{5}{8})\cos\phi + (\tfrac{1}{2})\cos\phi\cos(n\phi) - (\tfrac{1}{2})\cos\phi\cos(2n\phi) - (\tfrac{1}{2})\cos\phi\cos(3n\phi) - (\tfrac{1}{8})\cos\phi\cos(4n\phi)].$$

Integration of this sum gives

$$\int_{-\pi/n}^{+\pi/n} \cos\phi\,[(1/n)\sin(n\phi) + (1/2n)\sin(2n\phi)]^2\,d\phi = (1/n^2)\sin(\pi/n)\,[(5/4) - 1/(1-n^2) - 1/(1-4n^2) + 1/(1-9n^2) - \tfrac{1}{4}/(1-16n^2)].$$

The total work done by the external loads in consequence of the tangential displacements is therefore

$$W_{P\cdot t} = (\tfrac{1}{2})\,\pi^2\,(P/d)\,(r/L)\,\alpha^2 R_1 \quad . \quad . \quad . \quad . \quad (78)$$

where

$$R_1 = (\tfrac{1}{2}n^2)\sin(\pi/n)\,[(5/4) - 1/(1-n^2) - 1/(1-4n^2) + 1/(1-9n^2) - \tfrac{1}{4}/(1-16n^2)] \quad . \quad . \quad . \quad . \quad (78a)$$

(d) The Critical Load.

The critical load may be computed from the condition (*cf.* §16):—

$$W_P = W_{r\cdot tot} + W_{str\cdot tot} \quad . \quad . \quad . \quad . \quad . \quad (79)$$

With aid of equations (65), (70), (76) and (78) we get

$$(\tfrac{1}{2})\,\pi^2\,(1/d)\,(r/L)\,\alpha^2\,(M_1 + R_1)\,P_{cr} = (\pi/2)\,(1/r^3)\,N\alpha^2 E I_r M_2 + 2\,\pi^5\,(r/d)\,(EI_{str}/L^3)\,\alpha^2 M_3 \quad . \quad . \quad . \quad . \quad (80)$$

where

$$M_2 = 17\,n^3 - 10\,n + (2/n) \quad . \quad . \quad . \quad . \quad (80a)$$

$$M_3 = (1/n)$$

and M_1 is given by equation (76*a*), R_1 by equation (78*a*).

The critical end load acting on the most stressed stringer is therefore

$$P_{cr} = P_E\,[4\,\pi M_3 + (1/\pi^3)\,(1/\gamma)\,M_2]/(M_1 + R_1) \quad . \quad . \quad (81)$$

where P_E is the Euler load of the pin-ended stringer of the length L

$$P_E = \pi^2 E I_{str}/L^2 \quad . \quad . \quad . \quad . \quad . \quad (81a)$$

and γ is the form coefficient

$$\gamma = (r/L)^3\,(r/d)\,(E_{str}I_{str}/NE_rI_r) \quad . \quad . \quad . \quad . \quad (81b)$$

From equation (81) the critical load may be computed, if n and N are known. Since n and N characterise the wave lengths in circumferential and longitudinal directions, respectively, their values must be chosen so as to render the critical load a minimum. For any given value of N the minimum value of P_{cr} may be found by calculating the expression[36]

$$P_{cr} = P_E\,[4\,\pi\,(dM_3/dn) + (1/\pi^3)\,(1/\gamma)\,(dM_2/dn)]/[(dM_1/dn) + (dR_1/dn)] \quad (82)$$

---

[36] The minimum condition of the function

$$P_{cr} = F(x) = A(x)/B(x)$$

is given by

$$dF(x)/dx = [dA(x)/dx]/B(x) - [dB(x)/dx]\,[A(x)/B^2(x)] = 0$$

or

$$[dA(x)/dx] - [A(x)/B(x)]\,[dB(x)/dx] = 0.$$

This equation may be transformed into

$$P_{cr} = [dA(x)/dx]/[dB(x)/dx].$$

and solving it simultaneously with equation (81). The values of the differential coefficients are the following :—

$$dM_1/dn = -(\pi/n^2)\cos(\pi/n)\left[1 - 1/(1-n^2) + \tfrac{1}{2}/(1-4n^2) - 1/(1-9n^2) + \tfrac{1}{2}/(1-16n^2)\right] - 2n\sin(\pi/n)\left[1/(1-n^2)^2 - 2/(1-4n^2)^2 + 9/(1-9n^2)^2 - 8/(1-16n^2)^2\right] \quad . \quad . \quad . \quad . \quad (83a)$$

$$dR_1/dn = -(1/n^3)\sin(\pi/n)\left[(5/4) - 1/(1-n^2) - 1/(1-4n^2) + 1/(1-9n^2) - \tfrac{1}{4}/(1-16n^2)\right] - (\pi/2n^4)\cos(\pi/n)\left[(5/4) - 1/(1-n^2) - 1/(1-4n^2) + 1/(1-9n^2) - \tfrac{1}{4}/(1-16n^2)\right] - (1/n)\sin(\pi/n)\left[1/(1-n^2)^2 + 4/(1-4n^2)^2 - 9/(1-9n^2)^2 + 4/(1-16n^2)^2\right] \quad . \quad . \quad (83b)$$

$$dM_2/dn = 51n^2 - 10 - (2/n^2) \quad . \quad . \quad . \quad . \quad (83c)$$

$$dM_3/dn = -(1/n^2) \quad . \quad . \quad . \quad . \quad . \quad (83d)$$

It may be mentioned that the influence of the second term of equation (70*a*) has been neglected when computing the differential coefficient of M_3.

The numeric calculation has been carried out in the following way :—The values of M_1, R_1, M_2, M_3, and of their differential coefficients have been calculated for different values of n. Equating the right hand sides of equations (81) and (82) the corresponding value of γ has been found. Setting this value into equation (81) the critical load P_{cr} has been computed.

In Figs. 17 and 18 values of P_{cr}/P_E and n, respectively, are plotted against γ. When $\gamma = 0.08875$ the critical load is a minimum for $n = 1$. In this case $\phi_0 = \pi/n = 180°$, *i.e.*, the whole circumference of the cylinder becomes distorted at buckling. When γ is smaller than 0.08875 the solution of both simultaneous equations (81) and (82) gives values smaller than unity for n. Since these have no physical sense the condition $n = 1$ has been retained for all values $\gamma < 0.08875$. For such values, therefore, equation (81) becomes

$$P_{cr}/P_E = 5.33 + (0.1234/\gamma) \quad . \quad . \quad . \quad . \quad (84)$$

Since here a variation of P_{cr} is not possible, it is more likely than in case γ exceeded 0.08875, that some other assumptions for the distortions at buckling would render P_{cr} smaller.

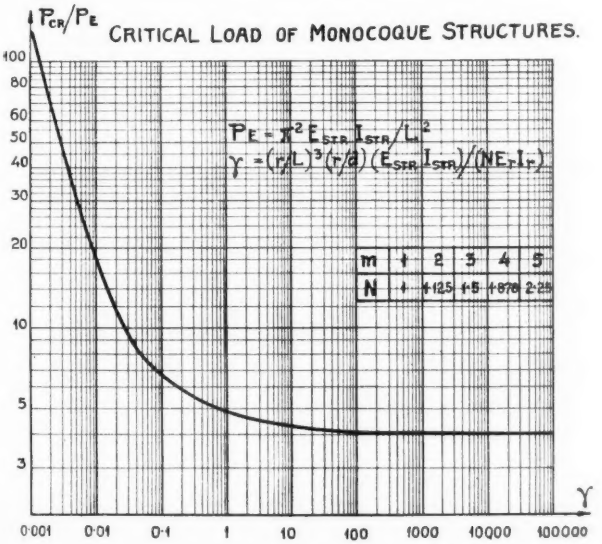

FIG. 17.

Figs. 17 and 18 show that in case of cylinders of large radius of curvature, closely spaced weak rings and closely spaced strong stringers (*i.e.*, for large values of γ) only a small portion of the cylinder becomes distorted at buckling (*i.e.*, n is large) and the critical load is only slightly higher for the same length L and for fully encastred ends than the buckling load of the most stressed stringer alone. In case of cylinders of small radius of curvature with widely spaced strong rings and widely spaced weak stringers the smallest value of the critical load corresponding to local buckling of the structure is obtained when the whole circumference of the cylinder is involved in buckling ($n=1$). Since, however, this value of P_{cr}/P_E is very high, in such structures the most stressed stringer is likely to buckle alone before failure by local buckling of the monocoque structure is possible.

§19. The Equivalent Length Diagram.

Fig. 17 represents all results necessary for calculating the critical load of monocoque structures in the case of local buckling, but it may not very conveniently be used. In practical computation several cases need be investigated, viz., several forms of buckling with 1, 2, or more rings involved. For every case the form coefficient γ must be computed, the Euler load P_E for the respective wave length L calculated and multiplied by the value of P_{cr}/P_E corresponding to the value of the form coefficient γ obtained.

In the following, therefore, another chart more convenient for practical use will be developed from the results plotted in Fig. 17.

The critical load of the most stressed stringer is given by

$$P_{cr}=(P_{cr}/P_E)\,\pi^2 E_{str} I_{str}/L^2.$$

This formula may be transformed into

$$P_{cr}=(P_{cr}/P_E)\,\pi^2 E_{str} I_{str}/(m+1)^2 L_1^2$$
$$=\pi^2 E_{str} I_{str}/L_1^2\,[(m+1)/\sqrt{(P_{cr}/P_E)}]^2,$$

what may also be written

$$P_{cr}=\pi^2 E_{str} I_{str}/(\lambda L_1)^2 \quad . \quad . \quad . \quad . \quad (85)$$

where λ denotes the equivalent length coefficient

$$\lambda=(m+1)/\sqrt{(P_{cr}/P_E)} \quad . \quad . \quad . \quad . \quad (85a)$$

where m is the number of rings within a wave length, L_1 the distance between two adjacent rings and rings are assumed to be equally spaced.

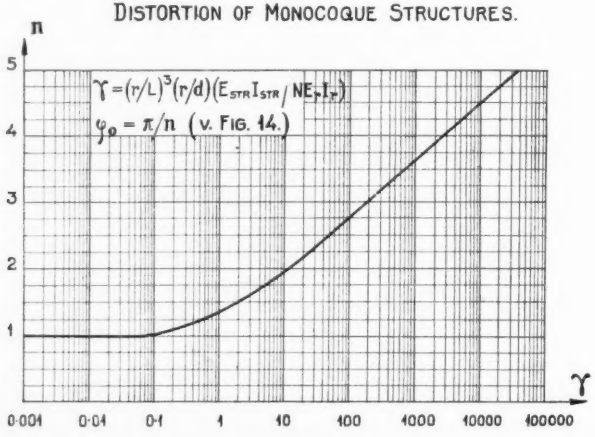

FIG. 18.

With the notation

$$\Lambda = (r/L_1)^3 \, (r/d) \, (E_{str} I_{str} / E_r I_r) \quad . \quad . \quad . \quad . \quad . \quad (86)$$

where Λ is the structure coefficient, a quantity analogous to the form coefficient γ, but calculated for the distance between adjacent rings, the value of Λ for any number m of rings involved may be calculated from the formula

$$\gamma = [1/(m+1)^3 \, N_m] \, \Lambda \quad . \quad . \quad . \quad . \quad . \quad (87)$$

Assuming several values for the structure coefficient Λ the values of the form coefficient γ corresponding to the number of rings involved

$$m = 1, \; 2, \; 3, \; 4 \text{ and } 5,$$

have been calculated with the aid of equation (87). The corresponding values of P_{cr}/P_E have been taken from Fig. 17 and the equivalent length coefficient λ computed from equation (85*a*). Results are plotted against Λ in Fig. 19. The diagram may be used in the following way for computing the critical load.

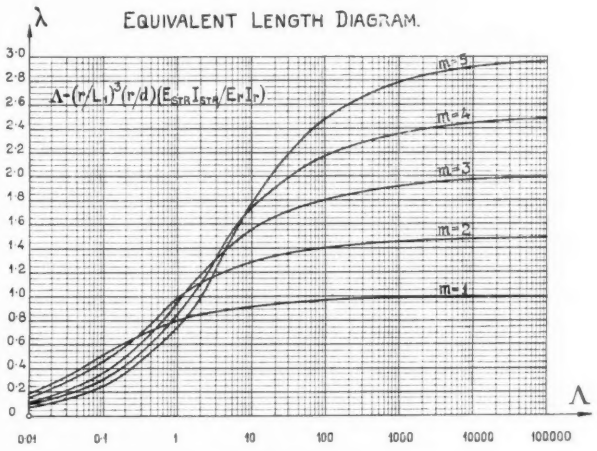

FIG. 19.

First the value of the structure coefficient Λ has to be determined from equation (86). If the number of rings within a wave length is not restricted, the highest possible value of λ corresponding to the value of Λ calculated has to be taken from the diagram of Fig. 19. The critical load of the most stressed stringer may then be obtained by substituting this value in equation (85), or alternatively the critical stress may be computed from the formula

$$p_{cr} = \pi^2 E_{str} / (\lambda L_1 / i_{str})^2 \quad . \quad . \quad . \quad . \quad (88)$$

where i_{str} is the radius of gyration of the stringer section and consequently $(\lambda L_1 / i_{str})$ the equivalent slenderness ratio.

In most practical cases, however, the number of rings in a wave length is limited by the fact that neither the dimensions nor the bending moments are constants for any greater length of the structure. In such case the probable number of rings involved must be assumed and the value of the equivalent length coefficient corresponding to this number taken from Fig. 19.

Equation (88) is very convenient for computations in case the critical stress p_{cr} exceeds the elastic limit of the material. In this case all deductions made so far retain their validity when putting τE_{str} for E_{str}, where τ is a coefficient dependent upon the stress p_{cr} and the elastic properties of the material. This coefficient has first been introduced by Professor von Kármán and the calculation of its

value may be found in a previous issue of this Journal.[37] When a strut chart is available for the stringer section used, the value of the critical stress may be taken from it directly for the corresponding equivalent slenderness ratio and the value of τ is not needed. This, however, is not the case when the structure coefficient Λ is calculated according to equation (86). Since, however, the equivalent length coefficient λ changes only slowly with varying structure coefficient Λ, as it may be seen from Fig. 19, in such cases it is sufficient to determine the value of τE_{str} only approximately.

Concerning the possibility of local buckling of cylindrical monocoque structures the following general conclusions may be drawn from Fig. 19. Since the free length of a stringer when buckling between two adjacent rings is between 1.0 L_1 and 0.5 L_1, corresponding to pinned and encastred ends, respectively, local buckling of the structure is not likely to occur for values of the structure coefficient lower than 0.1. Namely, in this case the equivalent length coefficient is smaller than 0.5 and consequently the load required for local buckling is always greater than necessary for strut failure of the stringer alone between two adjacent rings. For values of Λ greater than unity the equivalent length coefficient always exceeds unity if the number of rings involved may be equal or greater than 2. In such case local buckling of the monocoque cylinder occurs before strut failure of the stringer alone. It is, however, possible that some other form of instability occurs first, *e.g.*, buckling of the thin wall of the stringer.

Most fuselages hitherto constructed had structure coefficients below 0.1 and local buckling of the structure could not have been, therefore, very frequently observed. In order to obtain higher allowable stresses in fuselage structures, higher values of the structure coefficient are to be aimed at as long as the increasing expenses of riveting do not become prohibitive.

§20. Reliability of Results.

Values of the critical load obtained by the strain energy method cannot be regarded as exact solutions of the physical problem of buckling if the buckled form is obtained by variation of a parameter of an arbitrarily chosen expression for the deflections instead of by varying the functions which represent the deflections. Since, however, this latter method involves very lengthy and complex calculations, even in case an infinite series was chosen for the functions according to the Ritz method, since further other inexactitudes of calculation, material, and workmanship may also creep in, it has been considered a mere waste of work to aim at an exact solution of the mathematical problem. In the present paper, therefore, the minimum value of the critical load has been computed by varying only two parameters of an arbitrarily chosen expression. Consequently the minimum value found for the critical load is only a minimum consistent with the functions chosen and cannot represent the smallest possible value of the critical load.

The monocoque structure should, therefore, in reality buckle under smaller loads than calculated in the previous paragraphs had not other circumstances of an opposite effect been equally neglected in the calculations.

In §18 the stringers' share in the deformation energy due to tangential bending has been neglected for the convenience of calculations. Similarly the rings' share in the strain energy due to bending out of their plane and that of the sheet covering due to direct stresses has not been considered. This latter may, however, approximately be taken into account by calculating the effective width of sheet and considering in all calculations the combination of section plus effective width of sheet instead of the section alone, as already outlined in some detail in §15 for the case of flattening. All these items represent additional work to be carried out by the applied moment and raise, therefore, the value of the critical stress.

[37] Cf. §3 of Ref. 8.

The greatest deviation from calculation can be caused, however, in this case as well as in the case of flattening, by the occurrence of shear strain in the sheet covering. On the ground of the considerations of §15 it seems possible that in case of not very thin sheet covering the deformed shape of the structure and the value of the critical stress is influenced materially by this phenomenon.

For clearing up these problems definitely the only test carried out and described in Part IV is insufficient and more tests are needed. One series of tests should be carried out to ascertain experimentally the dependence of the equivalent length coefficient λ on the structure coefficient Λ, and another to investigate the effect of the thickness of the sheet covering in case of test pieces having the same value of Λ.

Should these tests show that the deviations from the present theory are considerable, an amended theory could be established by assuming distortions in better agreement with experiment and proceeding with calculations in the same way as in the present treatise.

In any case, though the agreement of the test described in Part IV with theory is not bad, it is advisable to use the results here obtained with caution, until they will be corroborated by further experiments.

In case of monocoque structures of non-circular cross section the results obtained should hold true approximately when substituting into the equations the radius of curvature of the structure at the most stressed stringer.

Here it may be mentioned that a similar problem has been dealt with by Dschou (v. Ref. 3), who calculated the critical load of orthogonally anisotropic curved panels in compression.

PART IV.

EXPERIMENTS.

§21. DESCRIPTION OF EXPERIMENTS.

With the aim to get a rough check on the theoretical results obtained in the body of the present paper concerning shape and magnitude of distortions and magnitude of stresses corresponding to the stable and instable forms of deformations of a cylindrical monocoque structure in bending, an experimental girder has been constructed and tested.

Shape and dimensions of the girder are shown in Fig. 20. Five equi-distant

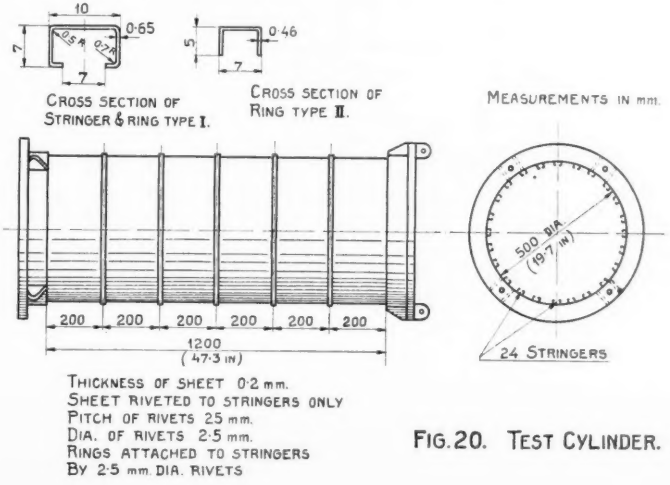

FIG. 20. TEST CYLINDER.

rings and 24 equi-distant stringers are provided and for both rings and stringers the larger section shown in Fig. 20 is used. For ease of calculation and construction the stringers are arranged internally and the rings externally to the cylindrical sheet of 0.2 mm. (0.00788in.) thickness which has an external diameter of 500 mm. (19.7in.). Since the broad sides of the sections of both stringers and rings are attached to the sheet, the values of the distances between the centroids of the sections and the axis of the cylinder are the closest possible to the nominal radius of the structure.

Stringer and ring sections are made of molybdenum steel. Strength tests yielded the following results:—

Tensile strength	4,870 kg. p. sq. cm. (30.9 tons p. sq. in.)
Yield point	4,180 kg. p. sq. cm. (26.5 tons p. sq. in.)
Elongation	15 per cent.

The carbon steel sheet has following characteristics:—

Tensile strength in direction of last rolling	8,340 kg. p. sq. cm. (53.0 tons p. sq. in.)
Tensile strength across direction of last rolling	7,050 kg. p. sq. cm. (44.7 tons p. sq. in.)
Yield point not observable.	
Elongation (in both directions) ...	2.1 per cent

The sheet is riveted to the stringers only, by means of carbon steel rivets of 2.5 mm. dia. (0.1in.) at a pitch of 25 mm. (approximately 1in.). Rings are fixed to stringers at their intersection points by rivets of equal dimensions, except that part of the cylinder where the greatest deformations due to local buckling of the structure may be expected and where, therefore, steel bolts of 3 mm. dia. (0.118in.) are used instead.

Each stringer end is fixed by means of three steel bolts of 3 mm. dia. (0.118in.) to a very rigid end ring, which practically cannot become distorted during test and is provided with an inserted steel piece and a copper packing in order to prevent gliding.

TESTING APPARATUS.

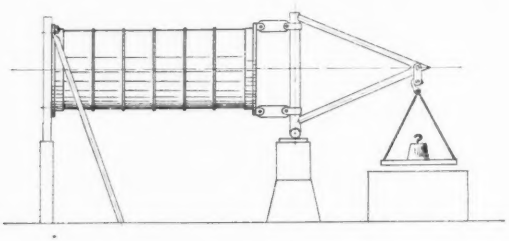

FIG. 21.

The arrangement of the testing apparatus is shown in Fig. 21. One end ring is bolted to a rigid plate supported by two standards, the other end ring is connected with two rods to a welded triangular frame resting on a stanchion and carrying the pan. By this arrangement the vertical load is balanced by the reaction at the stanchion and only a pure bending moment is transmitted to the test piece.

Changes in the lengths of both vertical and horizontal diameters of every ring have been measured at several stages of loading by means of a portable gauge having an aperture for measurements of slightly more than 500 mm. (19.7in.) provided with a dial micrometer allowing readings to 0.01 mm.

The greatest moment applied in the first test was 1,331.8 m. kg. (9,620 ft. lb.) corresponding to a weight of 1,331.8 kg. (2,930lb.) and a distance between weight and fulcrum of 1.0 m. (3.28ft.). Failure occurred by simultaneous buckling of several stringers at the compression side of the structure, as shown in Fig. 22. Every stringer involved formed several waves with half wave lengths equal to the distance between rings. Rings were not involved in failure. After removal of the loads a great part of the distortions disappeared.

FIG. 22.

Since in the experiments it was aimed at obtaining a failure of the form described in Part III, stringers have been straightened and rings removed and replaced by brass rings of the type II of Fig. 20. The properties of the material used are the following:—

Tensile strength	4,370 kg. p. sq. cm. (27.7 tons p. sq. in.)
Yield point	3,950 kg. p. sq. cm. (25.1 tons p. sq. in.)
Limit of elasticity	1,000-1,200 kg. p. sq. cm. (6.35-7.60 tons p. sq. in.)
Elongation	15.6 per cent.
Modulus of elasticity ...	1,050,000 kg. p. sq. cm. (6,660 tons p. sq. in.)

This modified test piece has been mounted in the inverted direction with the object to have the intact stringers on the compression side. It was to be expected that the deviations from the true form and the change in the properties of the material would cause some alterations in the behaviour of the cylinder under loads, but it was hoped that their influence on the phenomenon of local buckling of the structure would be small.

When tested again, this second girder collapsed under a load of 1,271.8 kg. (2,800lb.). Failure simultaneously occurred in three waves, as shown in Figs. 23 and 24. In longitudinal direction the wave length was equal to the threefold distance between rings, and therefore two rings were involved in the deformations.

After removing the loads part of the deformations of the stringers and of the sheet disappeared—the photographs have been taken after the loads have partially been removed—however, the brass rings were distorted permanently.

It should be pointed out that the test piece had not been constructed with special care and the deviations from the true form, therefore, were somewhat greater, than in real aircraft structures, when expressed in percentages of the main dimensions. This holds good, of course, to a much greater extent in the case of the

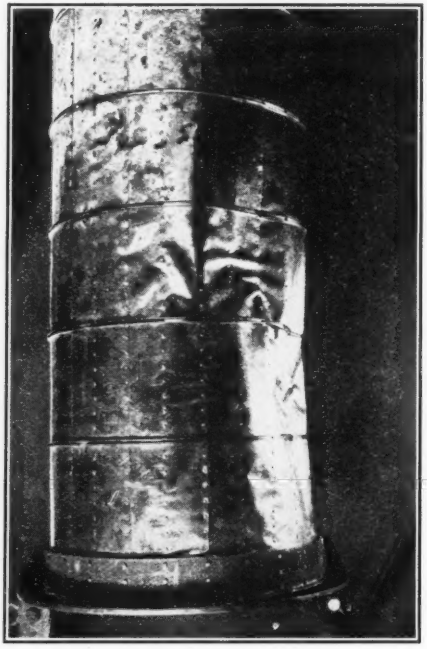

FIG. 23.

second (modified) girder for reasons already mentioned, and since the second set of rings has been fitted to the finished structure. Results obtained in the experiments described apply, therefore, to real aircraft structures and no allowance must be made for usual inaccuracy of workmanship. On the other hand, of course, the number of tests carried out was much too small for providing a reliable basis for the calculation of the local buckling of such structures.

§22. DISCUSSION OF TEST RESULTS.

(*a*) *Buckling of the Sheet.*

The formula of Redshaw[38] for the critical stress of a curved panel may be written in the following form:—

$$p_R = \sqrt{[\,p^2_{\text{curved}} + (\tfrac{1}{4})\,p^2_{\text{flat}}\,]} + (\tfrac{1}{2})\,p_{\text{flat}} \quad . \quad . \quad . \quad (89)$$

where p_R is the critical stress of the curved panel according to Redshaw, p_{curved} the critical stress of a tube of the same radius of curvature and thickness and p_{flat} the critical load of a flat sheet of the same breadth and thickness.

[38] V. Ref. 19.

According to Ebner[39] in the above formula, instead of the theoretical value, the practical critical stress of the tube should be used which may be put (v. §4)

$$p_{\text{curved}} = 0.3\, E\, (t/r) \quad . \quad . \quad . \quad . \quad (14)$$

In the present case, however, the sheet being of steel it is more advisable to make use of the formula of Donnell.[40]

$$p_{\text{curved}} = 0.6\, E\, (t/r) \times [1 - 1.7 \times 10^{-7}\, (r/t)^2]/[1 + 0.004\, (E/p_y)].$$

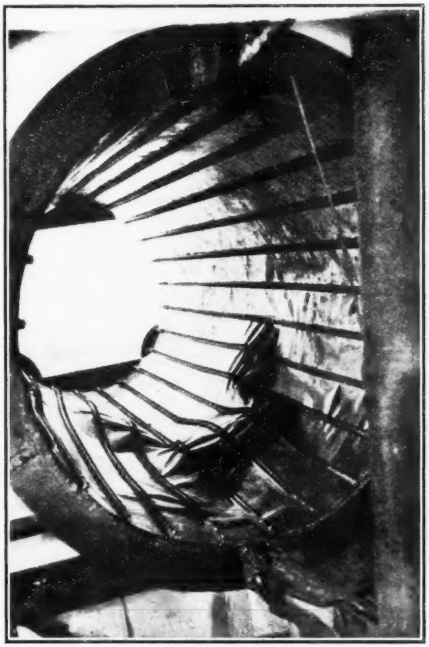

FIG. 24.

With $E = 2.1 \times 10^6$ kg. p. sq. cm. (13,300 tons p. sq. in.), $p_y = 7{,}000$ kg. p. sq. cm. (44.4 tons p. sq. in.) and $r/t = 250/0.2 = 1{,}250$ we get

$$p_{\text{curved}} = 0.2\, E\, (t/r) = 336 \text{ kg. p. sq. cm. (2.13 tons p. sq. in.).}$$

In fact, however, the theoretical radius of curvature of 250 mm. was not realised, since the sheet was attached only to the stringers between which it was much flatter. In the following we shall use, therefore, a three times smaller value:—

$$p_{\text{curved}} = 112 \text{ kg. p. sq. cm. (0.711 ton p. sq. in.)} \quad . \quad . \quad (90)$$

The critical stress of the flat panel is

$$p_{\text{flat}} = 3.62\, E\, (t/b)^2.$$

With $(b/t) = (65.5/0.2) = 327.5$ we get

$$p_{\text{flat}} = 71 \text{ kg. p. sq. cm. (0.45 ton p. sq. in.)} \quad . \quad . \quad . \quad (91)$$

By the formula of Redshaw we get

$$p_R = 152.9 \text{ kg. p. sq. cm. (0.965 ton p. sq. in.)} \quad . \quad . \quad (92)$$

[39] V. Ref. 4.
[40] Cf. p. 100 of Ref. 4.

In test a sudden buckling of a previously flat sheet could not have been observed due to the fact that starting out from initial irregularities the waves developed gradually.

(b) Stress Distribution in the Cylindrical Structure.

As long as the sheet does not buckle it may be supposed that the stress distribution is linear and the neutral axis passes through the centre of the circular section of the cylinder. After buckling of the sheet the load carrying capacity of the compression side of the cylinder decreases and the neutral axis, consequently, shifts to the tension side. Experiments have proved[41] that in such case stresses may also be calculated according to a linear law. After the assumption of a reduced value for the moment of inertia of the section and of a shift of the neutral axis the stresses in the different stringers can be calculated. The effective width of sheet may hereupon be determined on the ground of Part I. The assumption made for the shift of the neutral axis can be checked by the condition that the sum of tensile stresses and the sum of compressive stresses must be equal. Since any correction applied to the value of the shift involves modifications of the stresses in all stringers, of the effective widths and of the moment of inertia of the whole section, which in turn alters the stresses under a given load, the end result can only be obtained by successive approximations.

In the present case before buckling the moment of inertia of the section was

$$I_L = 2{,}100 \text{ cm.}^4 \ (50.6\text{in.}^4) \quad . \quad . \quad . \quad . \quad (93)$$

In case of a load of 1,300 kg. (2,860lb.) the moment of inertia is found to be

$$I_L = 1{,}750 \text{ cm.}^4 \ (42.2\text{in.}^4) \quad . \quad . \quad . \quad . \quad (94)$$

Since in this case the shift of the neutral axis is

$$s = 2.5 \text{ cm. (approximately 1in.)}$$

the moduli of the section are different for tension and compression and have the following values:—

$$Z_{\text{compr}} = 63.7 \text{ cm.}^3 \ (3.88\text{in.}^3) \quad . \quad . \quad . \quad . \quad (95)$$
$$Z_{\text{tension}} = 77.8 \text{ cm.}^3 \ (4.74\text{in.}^3).$$

(c) Stiffness Against Bending of Stringers and Rings.

The ratio of the panel width to the wave length of flattening being

$$(d/\lambda) = (6.55/120) = 0.0546,$$

we find from Fig. 11 that before buckling of the sheet the whole panel is effective. The increment of the moment of inertia of the stringer section due to the additional effective sheet is, however, small, since the centroid of the combined section shifts in direction of the sheet. Taking the curvature of the sheet duly into account, we get for the moment of inertia of the stringer against radial bending

$$I_{\text{str.I}} = 0.0082 \text{ cm.}^4 \ (0.000198\text{in.}^4) \text{ without effective sheet and}$$
$$I_{\text{str.II}} = 0.0107 \text{ cm.}^4 \ (0.000258\text{in.}^4) \text{ with effective sheet.}$$

In case of local buckling the wave length being smaller the values of the effective width and consequently of the moment of inertia of the combination are slightly smaller.

After buckling of the sheet the reduced effective width can be calculated on the ground of Part I of this paper. Carrying out the calculations for the same loading condition as under (*b*), viz., for $W = 1{,}300$ kg. (2,860lb.), and for the most stressed stringer, where $p_{\max} = 2{,}040$ kg. p. sq. cm. (13 tons p. sq. in.) we get

$$2\,w'/b = 0.25.$$

With this value the moment of inertia of the combination stringer section plus effective width becomes

$$I_{\text{str.II}} = 0.0100 \text{ cm.}^4 \ (0.000241\text{in.}^4) \quad . \quad . \quad . \quad (96)$$

[41] Cf. Ref. 4.

For the calculation of the buckling of the stringers alone and in the case of local buckling of the structure we shall use the above value. For the calculation of the flattening of the cylinder section, however, the tangential bending of the stringers must be also considered, as outlined in §8. Since the moment of inertia of the section against tangential bending is

$$I_{str\cdot t} = 0.0234 \text{ cm.}^4 \ (0.000564 \text{ in.}^4)$$

we get with aid of equation (26*a*)

$$I_{str} = I_{str\cdot r} + (\tfrac{1}{4})\, I_{str\cdot t} = 0.0140 \text{ cm.}^4 \ (0.000337 \text{in.}^4).$$

Lack of available data for this case we put the moment of inertia of the combination of stringer section plus effective width

$$I_{str} = 0.0180 \text{ cm.}^4 \ (0.000434 \text{in.}^4)$$

when calculating the flattening of the cylinder before buckling of the sheet and taking into account a proportional increment due to the effective width to that found in the case of radial bending alone.

After buckling of the sheet the influence of the tangential stiffness decreases, since the tangential displacements of the stringers are only maintained at the intersection points with rings. Since, however, deductions of Part II have been made on the assumption of the constancy of the moments of inertia during loading and throughout the whole structure, a mean value should best be used in calculations which may be put

$$I_{str} = 0.0160 \text{ cm.}^4 \ (0.000385 \text{in.}^4) \quad . \quad . \quad . \quad . \quad (97)$$

In case of the bending of the rings Metzer's results are not applicable, as outlined in §15. Even the methods of calculation of the effective width after buckling, as given in Part I, are not valid, since the curved fibres straighten in tension and buckle in compression. On the other hand, the fibres immediately adjacent to rings are prevented both from straightening and buckling and some small value of the effective width is, therefore, in this case also to be taken into account. The moment of inertia of the rings has, therefore, been put

$$I_r = 0.0100 \text{ cm.}^4 \ (0.000241 \text{in.}^4) \quad . \quad . \quad . \quad . \quad (98)$$

In case of the brass ring section the moment of inertia of the section alone is

$$I = 0.00186 \text{ cm.}^4 \ (0.0000448 \text{in.}^4).$$

Taking for the effective width the arithmetic mean between the value used for the steel ring and the double of this value—since in case of equal strain the steel sheet is twice as effective as would be a brass sheet—the moment of inertia of the combination of brass ring section and effective width becomes

$$I_r = 0.0027 \text{ cm.}^4 \ (0.000065 \text{in.}^4).$$

It is convenient to multiply this value by the ratio of the moduli of elasticity for brass and steel, viz., $\frac{1}{2}$, with the result

$$I_{red} = 0.00135 \text{ cm.}^4 \ (0.0000325 \text{in.}^4) \quad . \quad . \quad . \quad (99)$$

(d) Flattening of the Cylinder.

The measured values of the shortening of the vertical diameters of the rings are diagrammatically shown in Fig. 25. Since there is a considerable scattering of the points and since the deformations of end rings have not been measured, it is not possible to draw exactly the deflection lines. The approximation attained is, however, sufficient to see that near the encastred ends the deflections are greater, than according to a sine law. This means that the distorted shape assumed in §14 does not correspond to the minimum of the potential energy and the real deflections should, therefore, turn out greater than according to calculation. This conclusion can be verified with the aid of Fig. 26 where the maximum deflections as taken from the curves of Fig. 25 have been plotted against the loads. As it may be seen from Fig. 26 the maximum deflections of vertical and horizontal diameters are nearly equal for any stage of loading and can be connected by a straight line.

The measurements being unreliable at the beginning of the loading, we shall express the deflections as a function of the bending moments, making use of the slope of the dash-dotted line of Fig. 26 with no regard to the initial value when $W=0$. Since the axis of the ordinates is provided with a quadratic scale the expression obtained is a quadratic as follows:—

$$2c = 0.767 \times 10^{-6} W^2$$

where $2c$ is the deflection in mm. and W the load in kg. The distance between the line of action of the loads and the fulcrum being 1,000 mm. and the radius of the cylinder 250 mm. above equation may be written in the following form.—

$$(c/r) = 0.675\,(M/E)^2 \quad . \quad . \quad . \quad . \quad (100)$$

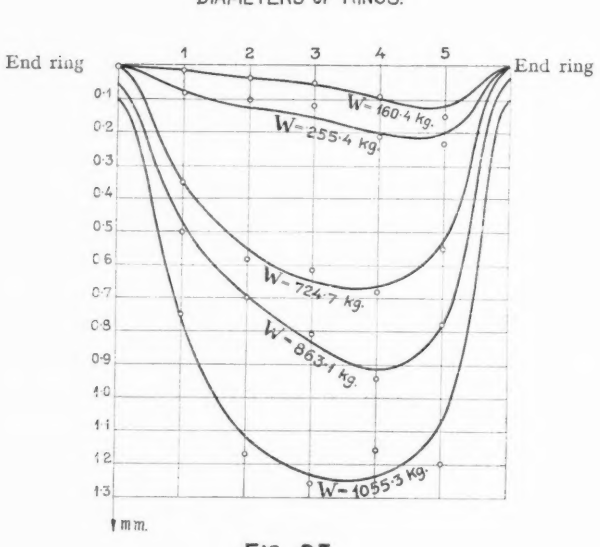

FIG. 25.

where M is the bending moment acting on the structure expressed in cm. kg. and E Young's modulus ($=2.1 \times 10^6$ kg. p. sq. cm.) or

$$(c/r) = 0.00252\,(M/E)^2 \quad . \quad . \quad . \quad . \quad (100a)$$

when M is given in in. lb. and E in lb. p. sq. in.

Substituting the values given by equations (97) and (98) into equation (51a) and assuming for the average value during test of the moment of inertia of the cylinder section $I_L = 1{,}900$ cm.^{4} (46in.^{4}) we get

$$\psi = 8\,\pi\,(1{,}900/25)\,[3 \times 0.45 \times (0.01/20) + (\tfrac{2}{3})\,\pi^4\,(25/120)^4 \times (0.016/6.55)] = 1.85.$$

Consequently the theoretical equation corresponding to the experimental result of equation (100) becomes on the ground of equation (51)

$$(c/r) = 0.54\,(M/E)^2 \quad . \quad . \quad . \quad . \quad (101)$$

if M expressed in cm. kg. and E in kg. p. sq. cm. and

$$(c/r) = 0.00201\,(M/E)^2 \quad . \quad . \quad . \quad . \quad 101a)$$

if M given in in. lb. and E in lb p. sq. in.

The agreement between both equations is surprisingly good when considering that the assumptions made for the deductions of §14 represent a very rough

approximation only. It may, therefore, be supposed that the results of §§10 and 11 are in still better agreement with reality and that all conclusions concerning magnitude of deflections and possibility of instability by flattening can be maintained with confidence. It shall, however, be pointed out that the effect of the sheet covering consists in decreasing the real displacements against the theoretical values and the comparatively good agreement can be the consequence of the simultaneous influence of the non-sinusoidal deflected form, which increases, and of the shearing stresses in the sheet, which decreases the distortions.

In case of the modified test piece the theoretical value of the coefficient of equation (101) is 1.35. This value was, however, not verified by the experiment. In the first stages of loading the cylinder flattened in such a way that the vertical

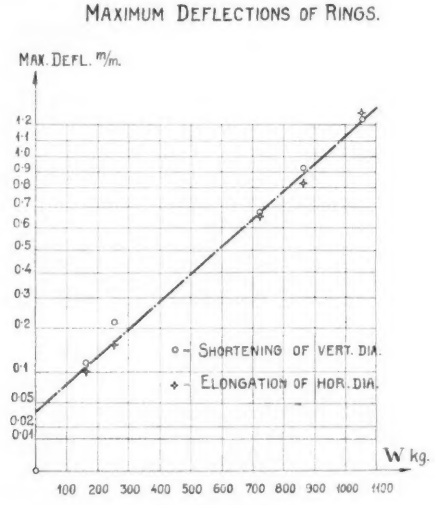

FIG. 26.

diameter lengthened and the horizontal shortened, especially at one end of the cylinder. This process became reversed only after a considerable load has been applied. From the slope of the deformations plotted against the loads a coefficient not very different from that obtained in the first test could be derived. This singular behaviour of the cylinder was probably due to the important permanent deformations which occurred during the first test.

(*e*) *Local Buckling of the Structure.*

The second test piece collapsed, as described in §21, into a form which in §16 has been denoted the local buckling of the structure. The load at collapse having been 1,271.8 kg. (2,800lb.), the distance between load and fulcrum 100 cm. (3.28ft.), and the modulus of the cylinder section $Z = 63.7$ cm.^{3} (3.88in.^{3}, *cf.* equation (95)), the compressive stress in the most stressed stringer becomes:—

$$p = 2{,}000 \text{ kg. p. sq. cm. } (12.7 \text{ tons p. sq. in.}) \quad . \quad . \quad (102)$$

The structure coefficient Λ can be calculated according to equation (86)

$$\Lambda = (25/20)^3 \, (25/6.55) \, (0.010/0.00135) = 55$$

making use of equations (96) and (99) and omitting the moduli of elasticity, since in equation (99) the reduced moment of inertia of the brass ring has been determined. With this value we get from Fig. 19

$$\lambda = 1.39.$$

The critical load, therefore, becomes according to equation (85)

$$P_{cr} = \pi^2 \times 2.1 \times 10^6 \times 0.010/(1.39 \times 20)^2 = 273 \text{ kg. (602lb.).}$$

The area of the combination of stringer plus effective width being 18.27 sq. mm. (0.0284 sq. in.) we get

$$p_{cr} = 273/0.1827 = 1{,}500 \text{ kg. p. sq. cm. (9.5 tons p. sq. in.)} \quad . \quad (103)$$

The deviation of this value from the experimental according to equation (102) is probably due to the influence of the sheet covering, especially to the shearing stresses in the sheet. This is also the possible cause of the fact that the wave length was three times the distance between rings, though according to Fig. 19 greater wave lengths should reduce the critical load.

The structure coefficient of the first test piece being

$$\Lambda = 7.4$$

the equivalent length coefficient becomes

$$\lambda = 1.22$$

for the case of a wave length equal three times the distance between rings ($m = 2$). With this value the critical stress of the most stressed fibre becomes

$$p_{cr} = 1{,}950 \text{ kg. p. sq. cm. (12.4 tons p. sq. in.).}$$

In consequence of the sheet covering the practical value is higher and, therefore, this type of failure could not develop the critical stress for strut failure, as shown under (*f*), being smaller.

A further deviation from the theoretical results is the smaller wave length than computed in tangential direction. From Figs. 23 and 24 it may be found that approximately 7-8 stringers were contained in a wave. This corresponds to values

$$n = 4 - 3.5.$$

With

$$\gamma = 1.82$$

according to equation (81*b*) we get from Fig. 18

$$n = 1.6.$$

This is a considerable deviation that too may be attributed to the effect of the sheet. The comparatively good agreement of the stress at buckling with the theoretical value, though the wave was much shorter in tangential direction than assumed, may be a consequence of the circumstance that calculations have been carried out with the aid of the strain energy method.

It is probable that in normal aircraft fuselages the agreement between theoretical and experimental results would be better, since the effect of the sheet covering is mostly smaller due to the relatively smaller thickness and curvature of the sheet and the greater size of panels allowing the sheet to become distorted under much smaller shear stresses after buckling. The clearing up of these problems would, however, necessitate a large series of tests.

(*f*) *Strut Failure of the Stringers.*

The first test piece collapsed by simultaneous buckling of a number of stringers, whereby intersection points with rings acted as nodes, as mentioned in § 21.

The greatest applied load being 1,331.8 kg. (2,930lb.), which corresponds to a maximum bending moment of 1,331.8 mkg. (9,620ft.-lb., *cf.* § 21) and the modulus of the cylinder section being according to equation (95) 63.7 cm.^{3} (3.88in.^{3}) we get

$$p_{max} = 2{,}090 \text{ kg. p. sq. cm. (13.3 tons p. sq. in.).}$$

The Euler load of a pin-jointed stringer of a length equal to the distance between rings is

$$P_E = \pi^2 \times 2.1 \times 10^6 \times 0.010/20^2 = 518 \text{ kg. (1,140lb.).}$$

The Euler stress is consequently

$$p_{cr} = 518/0.1827 = 2{,}840 \text{ kg. p. sq. cm. (18 tons p. sq. in.).}$$

It is interesting to determine which value of initial deviation of the stringer from the straight line is needed to reach the yield stress at some point of the stringer under the experimentally determined failing load. With aid of Perry's formula[42] we may write

$$p_y = d\,[P_E/(P_E - P)]\,Pa/I + P/A$$

where p_y is the yield stress of the material, d the initial deviation, P_E the above calculated Euler load, P the applied load, a the distance of the most stressed compressive fibre from the neutral axis, I the moment of inertia and A the sectional area of the stringer. With the values

$p_y = 4{,}180$ kg. p. sq. cm. (26.5 tons p. sq. in.).
$P_E = 518$ kg. (1,140lb.).
$P = 2{,}090 \times 0.1827 = 382$ kg. (840lb.).
$a_1 = 0.2$ cm. (0.0788in.).
$a_2 = 0.5$ cm. (0.197in.).
$I = 0.010$ cm.^{4} (0.000241in.^{4}).
$A = 0.1827$ cm.^{2} (0.0284 sq. in.),

we get

$$d = 0.72 \text{ mm. } (0.0284\text{in.})$$

if the stringer buckles in the inward direction and

$$d = 0.287 \text{ mm. } (0.0113\text{in.})$$

if the stringer buckles in the outward direction.

Such and greater values of initial deviations due to inaccuracy of workmanship were well possible. On the other hand, however, the strengthening effect of the sheet covering has been neglected.

Part V.

§23. Summary.

In the present paper two forms of instability of monocoque structures in pure bending have been discussed *in extenso*, viz., the flattening and the local buckling. For ease of calculation it is assumed that the structure is cylindrical, of circular cross section and consisting of a great number of evenly spaced uniform longitudinal stiffeners, denoted stringers and of several evenly spaced uniform transverse stiffeners, called rings.[43] The applicability of the results obtained to practical fuselages of non-circular cross section and the effect of different neglections have been dealt with in §§15 and 20.

I.—Preliminary to the discussion of the above problems, the results obtained by different authors concerning both the load carrying capacity of panels after buckling and the failure of stringers have been collected in Part I.

The load carrying capacity of stringers and buckled, originally plane, panels may best be allowed for by taking into account a combination of stringer section plus effective width of sheet assumed to be stressed uniformly, while the rest of the sheet is considered wholly ineffective. After calculation of the buckling stress of the panel

$$p_{cr} = 3.62\,E\,(t/b)^2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where E is Young's modulus of the material, t the thickness and b the breadth (perpendicular to the direction of the compressive load) of the panel, the value of the effective width $2w$ to be added to the section of the stringer may best be taken from Fig. 3, selecting the curve best suited to edge conditions. In Fig. 3 the values $2w/b$ obtained by several authors have been plotted against $\sqrt{(p_{cr}/p_{str})}$, where p_{cr} is the buckling stress of the panel as given by equation (2) and p_{str} is the stress in the stringer.

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[42] Cf. equation (36) of Ref. 8. Cf. also p. 91 et seq., Ref. 18.

[43] Cf. Fig. 5, where, however, the structure is drawn in the distorted form as assumed for the calculations of Part II. The test cylinder used for experiments is shown in Fig. 20.

For approximative calculations the formula of Professor von Kármán

$$2\,w/b = \sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

which gives results deviating to the safe side, may also be used.

Considering that the effective width decreases with increasing stress the values plotted in Fig. 3 must not be taken into account when calculating the reinforcing effect of the sheet against strut failure of the stringers. In such case the reduced effective width $2\,w'$ should be used instead. Values of $2\,w'/b$, as calculated by different authors, have been plotted against $\sqrt{(p_{cr}/p_{str})}$ in Fig. 4.

The following formula represents a safe approximation :—

$$2\,w'/b = (\tfrac{1}{2})\sqrt{(p_{cr}/p_{str})} \quad . \quad . \quad . \quad . \quad (11)$$

In §4 a corrected method for the practical computation of the failing load of plane panel and stiffener combinations has been suggested. Results hereby obtained are in good agreement with tests carried out at the M.I.T.

In case of curved panels the method suggested by Ebner (*cf.* §4, equations (13) and (14)) may be used which has been found to agree well with tests carried out at the D.V.L.[44]

II.—In Part II it is shown that the cross sections of monocoque cylinders flatten under bending moments in the same way as calculated by Brazier for the case of thin walled tubes. Making use of the notations of Fig. 5 the flattening ratio (c/r) of the rings becomes (*cf.* equation (35*c*))

$$(c/r) = (1/12\,\pi)\,(I_L/I_r)\,(p/E)^2$$

where I_L is the moment of inertia of the cross section of the structure about the neutral axis divided by the radius r of the cylinder, I_r the moment of inertia of the ring section plus effective width of sheet about the centroidal axis of the combination section plus effective sheet, divided by the distance between rings, p the stress in the most stressed stringer and E Young's modulus.

In case of normal monocoque fuselage structures the maximum value of the flattening ratio of the rings is not likely to reach the value

$$(c/r)_{max} = 0.02.$$

The additional flattening of the cylinder between adjacent rings (*cf.* Fig. 5) may be written (v. equation (36*c*))

$$(d/r) = (3/16\,\pi^5)\,(\lambda/r)^4\,(I_L/I_{str})\,(p/E)^2$$

where λ is the distance between adjacent rings and I_{str} is given by

$$I_{str} = I_{str\cdot r} + (\tfrac{1}{4})\,I_{str\cdot t} \quad . \quad . \quad . \quad . \quad . \quad (26a)$$

where $I_{str\cdot r}$ and $I_{str\cdot t}$ are the moments of inertia of the stringer section plus effective width of sheet about the centroidal axis of the combination against radial and tangential bending, respectively, divided by the distance between stringers.

In case of normal fuselages the maximum value of the flattening ratio of the portion of the structure between adjacent rings is not likely to attain the value

$$(d/r)_{max} = 0.0005.$$

Instability of monocoque structures by flattening was analytically found to develop at approximately the same value of the flattening ratio (v. Fig. 10) as calculated by Brazier for the case of thin walled tubes, viz., when

$$(c/r)_{cr} = (2/9) = 22.2 \text{ per cent.} \quad . \quad . \quad . \quad . \quad (41)$$

or, when considering a further term in equations,

$$(c/r)_{cr} = 0.259 = 25.9 \text{ per cent.} \quad . \quad . \quad . \quad . \quad (45)$$

A comparison of above values shows that the flattening ratios required by theory for the occurrence of instability can never be attained in case of monocoque fuselage structures.

All above calculations have been carried out on the assumption that rings are free to deflect. In case of any end constraint deflections are smaller. This problem has been dealt with in §14.

[44] Cf. also §22.

In some cases the stresses in the rings due to flattening reach considerable values. They may be computed from the formula

$$p_{r\cdot max} = 3\,(h/r)\,(c/r)\,E \quad . \quad . \quad . \quad . \quad . \quad (50)$$

where h is the distance between the most stressed fibre of the combination ring section plus effective sheet and the centroidal axis of the combination.

III.—In the case of monocoque cylinders of large radius provided with closely spaced weak rings and closely spaced strong stringers the most stressed stringer is not likely to buckle between adjacent rings, but forces several rings and stringers to become distorted simultaneously. This form of instability has been termed in the present paper local buckling of the structure and is shown in Figs. 15, 23 and 24. In such case the critical load of the most stressed stringer may be calculated from the formula

$$P_{cr} = \pi^2 E_{str} I_{str} / (\lambda L_1)^2 \quad . \quad . \quad . \quad . \quad . \quad (85)$$

where I_{str} is the moment of inertia of the stringer section (against radial bending),[45] E_{str} Young's modulus of the material of the stringer, L_1 the distance between adjacent rings and λ the equivalent length coefficient. This latter may be taken from Fig. 19 where it has been plotted against the structure coefficient Λ:—

$$\Lambda = (r/L_1)^3\,(r/d)\,(E_{str} I_{str} / E_r I_r) \quad . \quad . \quad . \quad . \quad . \quad (86)$$

where d is the distance between stringers, I_r the moment of inertia of the ring section[46] and E_r Young's modulus of the material of the ring.

If m the number of rings contained in one wave length is not restricted, the highest possible value of λ corresponding to the value of Λ obtained has to be taken from Fig. 19. In most practical cases, however, this number is limited by the fact that neither the dimensions nor the applied moments are constants for any greater length of the structure.

Alternatively the critical stress of the stringer may be computed from the following equation:—

$$p_{cr} = \pi^2 E_{str} / (\lambda L_1 / i_{str})^2 \quad . \quad . \quad . \quad . \quad . \quad (88)$$

where i_{str} is the radius of gyration of the stringer section and consequently $(\lambda L_1 / i_{str})$ the equivalent slenderness ratio. This equation may be used with advantage in the case when the critical stress exceeds the elastic limit of the material, since it retains its validity when setting τE_{str} into the numerator instead of E_{str}, where τ is the coefficient introduced by Professor von Kármán, as outlined in § 19. The critical stress may also be taken from a strut chart, if available for the section used, corresponding to the value of the equivalent slenderness ratio obtained. The structure coefficient Λ should, however, in such cases also be calculated with the value τE_{str} instead of E_{str}, but a small error in its value has only a minute effect on λ.

From Fig. 19 the conclusion may be drawn that local buckling of monocoque structures is to be expected when the value of the structure coefficient Λ is higher than unity and that local buckling cannot occur in case of values of Λ smaller than 0.1. All results concerning local buckling of the structure should, however, be used with caution until they will be reinforced by further experiments.

IV.—In Part IV some experiments are described which have been carried out in order to check the theoretical results obtained. In the first test the flattening ratio was found 25 per cent. higher and in the second test the critical stress at local buckling 33 per cent. higher than according to theory.

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[45] The effective width may also be added.
[46] Cf. footnote 45.

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ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 53. March, 1938.

The Principles of Aerial Warfare in U.S.S.R. 1—*Light and Heavy Bombers,* (XX, Luftwehr, Vol. 5, No. 1, January, 1938, pp. 2-8. From the Russian.) (53/1 U.S.S.R.)

The present instalment deals exclusively with heavy bombers which usually operate in formation and are intended for attack on targets well inside enemy territory. Suitable flight formations are described and illustrated. The object of the formation is to give mutual fire support and this may entail rapid changes depending on the method and direction of attack. In aerial combat it will always be the object of either side to manœuvre the opponent into a position which reduces the effectiveness of his fire. Examples of such manœuvres are given. It is held that if each individual bomber is supplied with sufficient guns and co-ordination is assured by proper training of the crews the bomber formation will have little to fear from fighter attack. In order, however, to reduce unnecessary strain of the bombing crew, it will be usual to escort the heavy machines by light bombers or fighters till they have passed the enemy lines and a similar escort will await their return.

The Machine Gun Installation on Ground Attack Aircraft. (From the Russian.) (N. J. Schaurov, Luftwehr, Vol. 5, No. 1, January, 1938, pp. 10-13. To be continued.) (53/2 U.S.S.R.)

Till quite recently, the machine guns in aircraft carrying out ground attacks were mounted parallel to the longitudinal axis of the aircraft. Previous to carrying out an attack, the aircraft had to climb to a certain altitude and the firing of the guns was carried out at relatively low altitude whilst the aircraft was diving towards the target. With modern high speed aircraft it will, however, be possible for the aircraft to fly on a parallel course above the target without being in any great danger of a hit. Ground attack under these conditions can be carried out by having the machine guns mounted so that they are permanently inclined downwards at a small angle. This method has the advantage that a number of aircraft can co-operate without any danger of collision.

Bomb Attacks on Railway Lines and Stations. (From the Polish.) (D. Mackiewicz, Luftwehr, Vol. 5, No. 1, January, 1938, pp. 13-17.) (53/3 Poland.)

When preparing a bombing attack on railway centres, it is essential that the operation be discussed with a traffic expert, so that the attack be concentrated

on those parts which will produce the greatest possible damage to the enemy. In order of importance, the following should be attempted:—

1. Total disruption of traffic over a given section for a given time.
2. Reduction in efficiency of a certain traffic section.
3. Destruction of accumulated stores.
4. Demoralisation of civilian population.

The author considers each of these aims in greater detail and concludes that although the destruction of a bridge or viaduct is obviously the most direct way of paralysing traffic, this destruction is difficult for aircraft, both on account of the nature of the target and the concentrated defences. A much better method will be to destroy sections of the line by dive-bombing attack. Although the damage done at each break is not great, the cumulative effect of such attacks will be serious. As regards attacks on stations, locomotive sheds and water towers should be picked out wherever possible. Attack on railway lines requires special bombs, suitable for both high and low altitude work. The fuses must be capable of various settings, including long delays. For ferro-concrete work, bombs of the order of 1,000 kg. will be required.

Optical Studies of the Motion of Machine Guns when Firing. (D. Kriedel, Luftwissen, Vol. 5, No. 2, Feb., 1938, pp. 49-52.) (53/4 Germany.)

A pointolite source of light is used and the motion of any particular part of the gun is studied by reflected light, using a small triple prism attached to the part in question. The prism operates by internal reflection and is designed so that the reflected beam records the displacement accurately without being affected by any small rotation or deflection of the part of attachment. Sample curves are shown for the motion of the breech, casing and barrel of a machine gun firing under various conditions. The displacement curves are stated to be sufficiently sharp to allow for first and even second differentiation.

Flight Experiments on the Boundary Layer. (B. M. Jones, J. Aeron. Sci., Vol. 5, No. 3, January, 1938, pp. 81-101, with discussion.) (53/5 U.S.A.)

The experiments were carried out partly on the "Hart" biplane and partly on a small monoplane, for a range of Reynolds numbers from four to ten million. The transition region, *i.e.* the region over which a change from laminar to turbulent boundary layer took place was located by means of an assembly of four pitot tubes situated at various distances from the wing surface such that three lie within the laminar layer and the fourth outside it, the whole set being situated at some fixed chord position on either the upper or the lower wing surface. If an alteration of flying conditions (lift coefficient) causes the transition region to traverse the pitot assembly, the pressure recorded by the outer pitot will fall, whilst the others show a rise in pressure. It appears that the transition region under flight conditions occupied about four inches of the wing profile (wing chord of the order of five to six feet).

From theoretical reasons it might be supposed that the transition point depends on the thickness of the laminar boundary layer, the pressure gradient in the layer and the curvature of the profile. From the experimental results, however, it appears that the conditions leading to transition cannot be expressed in terms of these three parameters. The actual parameters required are still unknown, but it seems likely that in some way transition is associated with laminar separation, and a possible reduction in surface friction is thus a question of laminar stability.

A Test Stand for the Investigation of Gust Effects. (T. Troller, J. Aer. Sci., Vol. 5, No. 3, January, 1938, pp. 113-6.) (53/6 U.S.A.)

The test stand of the Daniel Guggenheim Airship Institute consists of a 32-foot whirling arm, carrying a 10-foot model airship. The arm rotates at a distance

of 10 feet above the ground and the model is made to pass through the open jet of a 15 × 16-foot vertical wind tunnel. The air speed in the tunnel can be varied between 13 and 35 ft./sec., whilst the model travels at speeds ranging from 5 to 160 m.p.h.

The air flow round the model whilst passing through the gust is investigated by means of hot wire anemometers, whilst force measurements are carried out by the so-called " scratch " method. For this purpose the model is suspended on as many pairs of wires as there are force components requiring measurement and the extension of the wire transmitted by a suitable lever system to a diamond point moving over the surface of a glass cylinder. The records obtained in this way are then magnified optically and converted into force measurement by means of a calibration (stress/strain) diagram.

The Photographic Study of Flow Phenomena Around Obstacles. (C. Chartier, Pub. Sci. et Tech., No. 114, 1937, pp. 1-181.) (53/7 France.)

The author describes in detail the technique developed by him for obtaining the velocity field around obstacles exposed to a current of air or water. The flow is rendered visible by admixture with aluminium powder, a rotating sector (toothed wheel) giving a series of timed exposures. The source of illumination is provided by a special arc lamp and by introducing an intentional shock to the lens every time the camera shutter opens, the beginning of the flow lines (and hence the direction of the vectors) can be determined free from ambiguity. Some attempt at three-dimensional representation is made by taking stereoscopic views. Interesting examples of the flow round various obstacles (buildings, spheres, propellers) are given, both in the original state and in the form of vectorial diagrams.

On the Statistical Theory of Isotropic Turbulence. (T. v. Kármán and L. Howarth, Proc. Roy. Soc., Series A, Vol. 164, No. 917, 21/1/38, pp. 192-215.) (53/8 Great Britain.)

G. I. Taylor (1935), in a paper of fundamental importance, introduced the conception of isotropic turbulence and applied it, with interesting results, to the problem of the decay of turbulence in a wind stream.

The authors develop a general theory of isotropic turbulence. The correlation coefficients between two arbitrary velocity components at two arbitrary points form a tensor called the correlation tensor. Due to isotropy the tensor corresponding to one fixed and one variable point has spherical symmetry; due to the condition of continuity it is completely determined by one scalar function. The mean products of the derivatives of the velocity fluctuations are expressed by the derivatives of the tensor components; in this way laborious calculations for obtaining such mean values are eliminated. The correlation between three components (triple correlation) is discussed.

After developing the kinematics of isotropic turbulence the dynamical problem of the change of the various mean values with time is considered. It is shown that using the equations of motion a partial differential equation connecting the double and triple correlation functions can be established. The solution of this equation is investigated first in the case when the triple correlation is neglected and the shape of the double correlation function remains similar and only its scale changes. Equations for the dissipation of energy and vorticity are deduced.

Finally, a possible solution for large Reynolds numbers is given and applied to Taylor's problem of the decay of turbulence behind a grid.

Taylor's fundamental relation between the width of the correlation function and the size of the small (dissipative) eddies is confirmed. However, it is believed that the linear law for the reciprocal of the root mean square of the velocity fluctuations as a function of the distance from the grid is a special case; in the last section of the present paper a more general functional relation is suggested.

Instability of Fluids Heated from Below. (K. Chandra, Proc. Roy. Soc., Series A, Vol. 164, No. 917, 21/1/38, pp. 231-42.) (53/9 Great Britain.)

PART I.—A layer of air, having no initial mean motion and enclosed within a chamber, was made unstable by heating from below; and the motion produced, made visible by tobacco smoke, was studied for a range of depths of the chamber and of temperature differences between the top and bottom of the chamber. It was found that no motion occurred in the chamber unless the temperature difference exceeded a critical value, which varied with the depth of the chamber.

The new results obtained in Part I are:—

(*a*) That in depths down to 7 mm. the temperature difference necessary to produce motion such as was investigated in the Rayleigh-Jeffreys theory is in good accordance with the theoretical expression given by Jeffreys.

(*b*) That in all depths below 10 mm. a type of motion other than that discussed by Jeffreys occurs with lower differences of temperature than those given by Jeffreys' theory.

PART II.—When the air in the chamber was subjected to a shear by the motion of the top bounding plate across the chamber, it was found that the smoke patterns might show transverse rolls, distorted polygons, or longitudinal rolls, the precise forms depending on the magnitudes of the rate of shear and of the temperature differences within the chambers.

On the Velocity and Temperature Distributions in the Turbulent Wake Behind a Heated Body. (S. Goldstein, Proc. Camb. Phil. Soc., Vol. 34, Part I, 1938, pp. 48-67.) (53/10 Great Britain.)

The velocity distribution in the wake behind a body of revolution calculated on the momentum transfer theory is not in accordance with experiment.

There are two methods of simplifying the equation for the first approximation to the velocity defect u far downstream on the analogy of the successful simplification of the corresponding equation for the two-dimensional case. One method gives the same equation as if the turbulence were symmetrical; the other gives the equation of the modified vorticity transfer theory.

The first method gives fair agreement with experiment over the middle of the wake only, whilst the second does not agree with experiment at all.

The temperature distribution behind a heated body was calculated according to each of the foregoing theories.

The temperature distribution was also calculated from the experimental velocity distribution without any assumption being made concerning the kinematic coefficient of turbulent diffusion, which was eliminated between the equations for the velocity and temperature.

The vorticity transfer theory with symmetrical turbulence gives an impossible result. The modified vorticity transfer theory gives θ/θ max. $< u/u$ max. when the experimental max. velocity distribution is used.

The Spectrum of Turbulence. (G. I. Taylor, Proc. Roy. Soc., Series A, Vol. 164, No. 919, 18/2/38, pp. 476-90.) (53/11 Great Britain.)

It is shown that a definite connection exists between the spectrum of the time variation in wind at a fixed point in a wind stream and the curve of correlation between the wind variations at two fixed points. The spectrum curve and the correlation curve are, in fact, Fourier transforms of one another.

As an example of the use of this relationship the spectrum of turbulence in an American wind tunnel was calculated from measurements of correlation by Dryden. In some further experiments Dryden modified this spectrum by inserting a filter circuit and then measured the correlation with this filter in position. The modified spectrum is here calculated from the filter characteristics and the Fourier transform theorem is used to calculate the modified correlation curve. The agreement with Dryden's measurements is very satisfactory.

The paper ends with some remarks on the bearing of the spectrum measurements on the theory of dissipation of energy in turbulent flow.

On the Solution of Laminar Boundary Layer Equations. (L. Howarth, Proc. Roy. Soc., Series A, Vol. 164, No. 919, 18/2/38, pp. 547-579.) (53/12 Great Britain.)

PART I. The problem of the flow along a flat plate placed edgewise to a steady stream (when a retarding pressure gradient varying linearly as the distance x from the leading edge of the plate is superposed) is discussed. If y denotes distance measured perpendicular to the plate, a solution is obtained in the form of a power series in x whose coefficients are functions of $y/x^{\frac{1}{2}}$. Differential equations are obtained for these coefficients. Seven of the coefficients have been obtained with reasonable accuracy and the eighth and ninth roughly. Unfortunately it appears that about eight more terms are required to carry the solution to the point of separation; the work involved in their determination is prohibitive. Two approximate methods have been developed for determining the error when the first seven terms of the series are used as an approximation. These methods lead to the determination of the point of separation and are in agreement as to its position. If b_0 is the velocity at the edge of the boundary layer at the leading edge of the plate and b_1 is the velocity gradient, separation is found when $b_1x/b_0=0.120$.

PART II. A method is developed for the solution of the boundary layer equations in any retarded region. It is obtained by replacing the velocity distribution at the edge of the boundary layer by a circumscribing polygon of infinitesimal sides and applying the preceding solution to each of these sides, making the momentum integral continuous at each vertex. The problem is thereby reduced to the solution of a first order differential equation.

Air Flow Round a Bird in Flight—Simultaneous Cinematographic Records in Three Planes at Right Angles to Each Other. (A. Magnan and others, Comp. Rend., Vol. 206, No. 6, 7/2/38, pp. 462-464.) (53/13 France.)

The experiment consists in causing a bird to fly in a glass box (1.10 m. side) and recording the motion photographically in three directions, the air current being rendered visible by introducing jets of tobacco smoke.

The air within a radius of at least 50 cm. of a pigeon in flight (60 cm. span) is aspirated towards the body of the bird (from above, front and below).

This inflow appears to be continuous, whilst the outflow of the air (mainly towards the rear, *i.e.*, opposed to direction of flight) is discontinuous with a periodicity corresponding to the wing beats.

The bird in flight leaves a trail of vortices in its wake, the axes of which are situated on the line of intersection of the plane of symmetry of the bird with its tail plane.

Model Experiments on the Flow of the Gases in Pulverised Fuel Boilers. (F. Schultz-Grunow, Forschung, Vol. 9, No. 1, Jan.-Feb., 1938, pp. 41-8.) (53/14 Germany.)

The object of the experiments was to trace out the path of the flame in the full scale boiler so as to obtain data on the probable localisation of ash deposits.

In the model, a propane flame was employed, which has a similar density to the coal dust mixture. Only approximate similarity between the model and full scale could be obtained, since exact similarity in such a complicated process necessarily entails correspondence in a large number of critical parameters.

The report contains flame photographs under a variety of operating conditions from which the full scale behaviour can be estimated.

In a later report the author proposes to deal with an extension of the method to other types of flow accompanied by thermal changes.

Model Balance for the Rapid Determination of the C.G. of Aircraft. (De Havilland Gazette, No. 10, February, 1938.) (53/15 Great Britain.)

The aircraft is represented by a beam which is weighted to represent the tare weight and tare C.G. position to some suitable scale. The beam is supported on a fulcrum whose position is adjustable over the C.G. range. The beam which is nothing more or less than a model of the aircraft, is fitted with pegs at the positions of disposable load items (crew, fuel, oil, passengers, luggage, etc.), upon which are hung weights representing these items. The position of the fulcrum is then adjusted until the beam balances level as indicated by a pointer, whereupon the C.G. position is indicated on the scale, upon which the permissible limits are marked. Conversely, the fulcrum may be set to a given C.G. position and the beam loaded up until it is in balance; the disposition of weights then gives the loading to produce this C.G. position.

Spinning Characteristics of Wings V—N.A.C.A. 0009, 23018 *and* 6718 *Monoplane Wings.* (M. J. Bamber and R. O. House, N.A.C.A. Tech. Note No. 633, Jan., 1938.) (53/16 U.S.A.)

Three rectangular monoplane wings having rounded tips were tested on the N.A.C.A. spinning balance in the 5 foot vertical wind tunnel. The aerofoil sections used were the N.A.C.A. 0009, 23018 and 6718.

The aerodynamic characteristics of the models and a prediction of the angles of sideslip for steady spin are given. There is included an estimate of the yawing moment that must be furnished by parts of the aeroplane to balance the inertia couples and wing yawing moments for spinning equilibrium. The predicted angles of sideslip and yawing moments required for spinning equilibrium for a Clark Y wing with the same plan form are included for comparison.

The Icing-up of Aircraft. (W. Stippler, Z.V.D.I., Vol. 82, No. 7, 12/2/38, pp. 161-4.) (53/17 Germany.)

The article contains interesting photographs showing ice formation on wings, control surface, bracing wires and such auxiliaries as oil cooler, carburettor intake and pitot tubes.

Wing deicing devices, such as the Goodrich and Dunlop are described.

The German Lufthansa have carried out experiments with exhaust heating, which are stated to have given satisfactory results. (See Translation No. 535.)

Light high speed metal propellers generally vibrate in flight and this prevents icing troubles. With the advent of larger slow speed propellers, special precautions are required.

Icing conditions can generally be expected if the air is between 0° and $-5°$ C. and if the moisture content of the air is sufficient.

With adequate meteorological data and experience, the pilot will often be able to shape his course so as to avoid dangerous conditions.

The problem is of extreme importance and it is hoped that by international co-operation and exchange of experience a satisfactory solution will be obtained in the near future.

The Focke Helicopter. (H. Focke, Luftwissen, Vol. 5, No. 2, Feb., 1938, pp. 33-39. Full translation in preparation.) (53/18 Germany.)

The author gives some account of the development work carried out by him over the last five years and which culminated in the successful public demonstration of his helicopter last year.

Reasons for adopting a side by side arrangement of the lifting rotors instead of the superposition employed by previous investigators are given. The demonstration model was built throughout to conform to the German aircraft strength specifications so that, in addition to beating previous performances by a very large margin, the machine was also awarded an airworthiness certificate.

In this connection it is interesting to note that the driving gear and blade incidence mechanism was subjected to a 50 hours type test on similar lines to engine type tests. The Focke blade control is such that in case of engine or gear failure, or if the speed of rotation of the rotor falls below a certain minimum, the rotor is automatically disconnected and the blade incidence adjusted to set up autorotation. The machine has repeatedly landed under conditions of autorotation as well as under power (landing as a helicopter) and it is claimed that this is the first time that this essential feature has been demonstrated for any helicopter. The Focke helicopter has also been flown as a pure " autogiro " by fitting a power propeller to the engine instead of the normal cooling fan and it is interesting to note that much greater translational speeds could be obtained when the machine operated under helicopter conditions.

Tank Tests of a Model of One Hull of the Savoia S-55-X Flying Boat—N.A.C.A Model 46. (J. M. Allison, N.A.C.A. Tech. Note No. 635, January, 1938.) (53/19 U.S.A.)

A model of one of the twin hulls of the Italian Savoia S-55-X flying boat (N.A.C.A. model 46) was tested in the N.A.C.A. tank according to the general method. The data obtained from the tests cover a broad range of speeds, loads, and trims and are given in non-dimensional form to facilitate their use in applying this form of hull to any other flying boat or comparing its performance with the performance of other hulls. The results show that the resistance characteristics at best trim of this model are excellent throughout the speed range. In order to compare the performance of the S-55-X hull with that of model 35, a pointed step hull developed at the N.A.C.A. tank, the data are used in the computations of a take-off example of a twin hull, 23,500-pound flying boat. The calculations show that the S-55-X has better take-off performance.

Operating Technique on Helium Filled Airships. (H. Eckener, J. Aeron. Sci., Vol. 5, No. 3, January, 1938, pp. 107-108.) (53/20 Germany.)

In the previous hydrogen filled ships (Graf Zeppelin and Hindenburg) the weight of fuel consumed was balanced by deliberate valving of hydrogen. As helium is 10 times as expensive as hydrogen, it will be necessary in the next Zeppelin airship filled with helium, to fit a water ballast recovery plant. Tests at Friedrichshafen have shown that there will be no difficulty in recovering sufficient water from the exhaust of the Diesel engines employed.

Whilst the water recovery plant meets the case of flying at constant altitude, it remained still necessary to prevent loss of expensive helium when taking off from the ground and rising to the operative height. This final difficulty will be overcome by preheating the gas electrically before the ascent. At the operative height, the gas will cool rapidly and this will compensate for the reduction in pressure. It is hoped by this means, to reduce the helium losses to those unavoidably associated with diffusion and subsequent purification. The total loss will not exceed 10 per cent of the total gas consumption of the previous hydrogen filled ships and the operative cost with helium should therefore not exceed the previous hydrogen figure.

A Mechanical De-icer. (M. Gosselin, Les Ailes, No. 872, 3/3/38, p. 7.) (53/21 France.)

The proposed device resembles to some extent the well known Goodrich de-icer, except that the periodic bulging of the wing " over-shoe " (which causes the ice to break off) is not brought about by a cyclic variation in air pressure, but by the motion of a small carriage which is pulled along rails below the rubber cover.

A number of these carriages are in series and an equal number of receptacles are provided in the wing below the rubber cover. The total " stroke " of the

assembly is about 1 m., and when the carriage drops in the receptacle, the outer cover presents a smooth appearance.

It is claimed that one to-and-fro motion of the assembly brought about by a suitable wire control will remove all the ice along the nose of a wing.

Theoretical Study of the Motion of Aeroplanes Following Initial Disturbances. (Fr. Haus, Bulletin du Service Technique de l'Aeronautique, No. 17, June, 1937, pp. 3-72.) (53/22 Belgium.)

The author calculates the longitudinal and lateral motion of an aircraft of given stability parameters when subjected to certain initial disturbances (change of flight path, change of incidence, change in angle of bank, meeting of horizontal and vertical gusts, etc.).

The theoretical calculations are compared in certain cases with actual flight experiments, the agreement being satisfactory.

It appears that after a change of incidence from any cause, the incidence is very rapidly restored whilst the accompanying disturbance in speed and flight path takes an appreciable time to settle down.

Of special interest is an extension of the results to the possibility of improving the longitudinal stability of a given aircraft by means of a wind vane responding to changes in incidence or to side slip.

North Atlantic Air Service—London-Montreal. (J. H. Parkin, The Engineering Journal, Vol. 20, No. 8, August, 1937, pp. 611-647.) (53/23 Canada.)

After a careful survey of various possible routes from the point of view of weather and length of sea passage, the author favours the route via Limerick and Botwood. This route has a total length of 3,325, which is within 70 miles of the great circle route, the actual sea passage being 1,900 miles.

An interesting descriptive review of some 70 types of large civil aircraft is given, together with their relative transport efficiencies in ton miles per horse-power. It appears that high transport efficiency is necessarily associated with high wing loading together with moderately high power loading. Various means of overcoming take-off difficulties are discussed, including composite aircraft. It is considered that the catapult presents the simplest and cheapest solution.

An urgent plea for the development of the oil engine is made, since this type is considered specially suited for transatlantic work.

The article also contains an interesting survey of the icing problem and means to be adopted for minimising this danger.

The Behaviour of Compression-Ignition Engines in a Rarefied Atmosphere. (P. Clerget and R. Marchal, Comp. Rend., Vol. 206, No. 6, 7/2/38, pp. 420-423.) (53/24 France.)

Flight experiments were carried out on a Clerget radial oil engine, C.R. 14.5, rated 500 B.H.P. at 2,700 m. and 1,900 r.p.m.

The engine was fitted with a supercharger reproducing ground level pressure at 2,700 m.

The fuel pump was set to give the normal mixture strength (25/1) at this altitude and an altitude of 7,650 m. was reached without touching either air or fuel controls. It was noticed that the engine r.p.m. increased with altitude up to 6,000 m. and remained practically constant up to the ceiling. In the case of a petrol engine of similar rating, the engine r.p.m. fell off immediately the supercharged height was exceeded.

The difference in behaviour is explained by the Diesel engine being able to burn richer mixtures at altitude, the mixture strength increasing from 25/1 at 2,700 m. to 14/1 at 6,000 m.

Neither low temperature nor low pressure of the atmosphere thus affect the aircraft Diesel engine deleteriously. Scavenging of the combustion space is very

effective and in this connection the application of the exhaust driven supercharger to the aircraft Diesel appears specially promising.

Liquefied Air Used to Run a Boat Engine. (J. Frank. Inst., Vol. 225, No. 2, Feb., 1938, pp. 250-1.) (53/25 Japan.)

The engine, invented by a Japanese engineer, consists of a container of liquefied air, a pump, a vaporiser, a prime mover and a liquefier. The liquefied air in the container is led into a vaporiser through the pump. The pump is made of a copper alloy, and is capable of withstanding the low temperature without freezing or cracking. The vaporised air leaving the prime mover is again liquefied, the operation being thus continuous, except for the addition of a small quantity of air in order to make up for the leakage from valves and other connecting parts of the system. The invention is considered of great practical importance, and in addition to the demonstration model, a larger unit is under construction.

Influence of Number of Blades on the Performance of Centrifugal Supercharger. (I. Watanabe, H. Sibata, Y. Makagawa and D. Toyozawa, Aer. Res. Inst., Tokio, Report No. 159, December, 1937.) (53/26 Japan.)

This paper describes the effect of number of blades on the performance of a centrifugal supercharger. Experiments were carried on eighteen, nine and six-bladed model impellers, and sixteen, eight and four-bladed full scale impellers. The results of these experiments showed that the greater the number of blades, the better the performance of the supercharger, *i.e.*, the overall adiabatic efficiency, pressure ratio, density ratio, etc., are all increased. It appears therefore that the number of blades should be increased to the limit set by the minimum induction area required.

The Combustion Process in the Lanova Diesel Engine. (F. Dreyhaupt, Forschung, Vol. 9, No. 1, Jan.-Feb., 1938, pp. 1-13.) (53/27 Germany.)

The Lanova Diesel engine has two air chambers in series forming a lateral extension of the combustion head. Communication between these chambers is restricted and the fuel spray is directed towards the entrance of the first chamber. The experimental engine had 100 mm. bore and 160 mm. stroke, C.R. 12.5 and piezo-electric indicator diagrams were taken simultaneously both for the main combustion chamber and for each air chamber. It appears that combustion is initiated in the air chambers and that the working process of the engine differs considerably from that described in the patent claims. The author investigated the effect of small dimensional changes in the size of the air chambers and in their relative position with regard to the injection nozzle. In this connection reference is made to previous bomb experiments by Petersen, which are in substantial agreement with those of the author.

The Problem of Flywheel Effect and Speed Regulation for Diesel Engine Driven Machinery. (A. D. Andriola, Trans. A.S.M.E., Vol. 60, No. 2, Feb., 1938, pp. 119-125.) (53/28 U.S.A.)

The author points out that the analysis of the flywheel problem most commonly used is based upon the assumption that the shafting connecting the various masses is infinitely rigid, and that there is no agreement on whether or not the engine, flywheel and generator mass are to be accounted for, the usual opinion being that the flywhel and engine only enter into the result. Attention is called to the fact that the inherent errors of the ordinary solution have been exposed by several authors, but that no specific attempt has been made to compare quantitatively the results obtained by the correct solution with those as ordinarily calculated. The author discusses both solutions of the problem, and compares results obtained with torsiographic data taken on actual installations.

Determination of the Rate of Discharge of Jerk Pump Fuel Injection Systems. (K. J. de Juhasz, Trans. A.S.M.E., Vol. 60, No. 2, Feb., 1938, pp. 127-136.) (53/29 U.S.A.)

The performance of a jerk-pump fuel-injection system under varied operating conditions is analysed by the graphical method developed by the author. Effect of open and closed nozzles, of varying orifice sizes, of pump-speed, of pipe-diameter, of pump delivery rate are discussed. The experimental equipment constructed at the Pennsylvania State College is described, which measures the rate of discharge by the stroboscopic method.

Proposed New Aero Engine with Double Propeller Drive and Fitted with a Cannon. (Les Ailes, No. 872, 3/3/38, p. 7.) (53/30 France.)

The two propellers are placed so that one is immediately behind the other. Both propeller shafts are hollow, the front propeller shaft passing inside the rear driving shaft. The rear ends of both shafts are fitted with spur wheels, and geared together by means of intermediate pinions, the assembly thus resembling a car differential. Each of the intermediate pinions is driven directly by an opposed twin cylinder engine (liquid cooled), the cylinder axis being parallel to the propeller shaft. The proposed design has six of these units arranged symmetrically round the propeller connecting gear. The complete engine thus consists of 12 cylinders, 160 mm. bore and 110 mm. stroke running at 3,600 r.p.m., whilst the propellers rotate in opposite directions at 1,800 r.p.m. The engine is rated at 900 B.H.P., the external diameter of the unit being only 88 cm. The aircraft cannon will fire through the hollow central propeller shaft.

Aircraft Diesel Engines. (Les Ailes, No. 872, 3/3/38, pp. 7-8.) (53/31 France.)

Whilst there is no doubt that the Diesel engine presents important advantages from the point of view of fuel consumption and fire danger, the mechanical difficulties associated with this design do not appear to have been overcome as far as concerns the aircraft model. One of the main troubles is associated with the piston and rings and it is stated that after each recent transatlantic flight, the pistons of the Junkers Diesel engine had to be withdrawn for adjustment. It appears that these engines will not operate continuously for more than 30 hours without requiring attention and that the firm of Junkers had to stop series production of 1,500 Jumo engines in view of the complaints of users.

Nevertheless, research and development is proceeding actively, especially in the U.S.A., where it appears that under supercharged conditions, mean effective pressures of the order of 18 kg./cm.^{2} (257 lb./sq. in.) have been successfully held in the case of a 4 stroke engine (185 lb./sq. in. for a 2-stroke engine). Such a performance is greatly in excess of what is possible with spark ignition engines and opens up fresh prospects for the use of the Diesel in aircraft, provided the time between overhauls can be made commensurable with that of the petrol engine. It appears that the French Air Ministry has also paid some attention to a bifuel engine of medium compression ratio (10/1). This is intended to operate under spark ignition (high octane fuel) when taking off and revert to oil injection when cruising.

Hot Spot Ignition in Internal Combustion Engines. (M. Serruys, Pub. Sci. et Tech., No. 115, 1937, pp. 1-44.) (53/32 France.)

The experiments were carried out on a single cylinder water cooled engine, 85 mm. bore, 140 mm. stroke, which could be fitted with three types of cylinder heads, designated respectively as non-turbulent, semi-turbulent and turbulent. The hot spot consisted of the closed end of a thin walled steel tube of approximately 1 cm.^{2} area provided with a thermocouple. By means of an electric current (low voltage) sufficient heat could be generated in the tube to raise its temperature to

above 1,000° C. For the detection of auto-ignition the following procedure was adopted: The engine is allowed to reach steady condition with every tenth explosion cut out by means of a suitable short circuiting device. This intentional miss is easily detected by ear and will disappear if the temperature of the hot spot is sufficient to initiate auto-ignition. With standard petrol fuel this temperature is of the order of 900° C. at 1,200 r.p.m. on full throttle.

The author has investigated the effect of various factors on the temperature of auto-ignition (turbulence, r.p.m., compression ratio, type of fuel, octane No., etc.). A lowering of the r.p.m. reduces the auto-ignition temperature very considerably in the case of a high turbulence combustion chamber, but has scarcely any effect for the low turbulence head. The presence of ethyl fluid raises the auto-ignition temperature appreciably.

Inter-Relation of Exhaust Gas Constituents. (H. C. Gerrish and F. Voss, N.A.C.A. Report No. 616, 1937.) (53/33 U.S.A.)

An investigation was made to determine the inter-relation of the constituents of the exhaust gases of internal combustion engines and the effect of engine performance on these relations. Six single-cylinder liquid-cooled test engines and one nine-cylinder radial air-cooled engine were tested. Various types of combustion chambers were used and the engines were operated at compression ratios from 5.1 to 7.0, using spark ignition, and from 13.5 to 15.6, using compression ignition. The investigation covered a range of engine speeds from 1,500 to 2,100 r.p.m. The fuels used were two grades of aviation petrol, Auto Diesel fuel and Laboratory Diesel fuel. Power, friction, and fuel consumption data were obtained from the single-cylinder engines at the same time that the exhaust gas samples were collected.

Definite relations, which were independent of engine design and operating conditions, were found among the constituents of exhaust gases, air-fuel ratio, water of combustion, and combustion efficiency. Combustion efficiency and amount of water combustion increased approximately linearly with air-fuel ratio for rich mixtures and were independent of mixture strength for lean mixtures. These relations make it possible to obtain a complete exhaust-gas analysis simply by determining the air-fuel ratio or the CO_2 and O_2 content. The results also showed that compression ignition engines may be operated at the same air-fuel ratio as spark-ignition engines without loss in combustion efficiency.

Improvement in Knock Rating by the Injection of Anti-Detonating Liquids into the Induction Pipe of Spark Ignition (Carburettor) Engines. (M. Pilon, Les Ailes, No. 870, 17/2/38, p. 7.) (53/34 France.)

The author claims that a higher knock rating results if the anti-detonating liquid (vaporised by means of hot exhaust) is introduced separately into the induction pipe (*i.e.*, between carburettor and engine) than if mixed with the fuel directly.

Moreover, this direct mixing may not be possible (lack of solubility of dope with parent fuel) and the separate injection thus widens the range of possible anti-detonating liquids. The experiments were carried out on the C.F.R. engine, the principal anti-detonating liquids being acetone ethyl alcohol, hydroquinone, camphor, water, benzol, etc.

The best results were obtained by adding 20 per cent. of aqueous alcohol solution containing a small proportion of lead tetraethyl (1 cc. per litre). In this case the octane number could be raised from 69 to 92.

It is stated that full scale experiments with a K.14 engine showed that benefit resulting from separate injection is relatively greater. The method appears especially promising in the case of iso-octane which does not vaporise readily and produces difficulty if mixed with the fuel direct.

Water Tolerances of Mixtures of Petrol with Ethyl Alcohol. (O. C. Bridgeman and E. W. Aldrich, Bur. Stan. J. Res., Vol. 20, No. 1, Jan., 1938, pp. 1-8.) (53/35 U.S.A.)

Equations, based on 23 different petrols, have been developed for calculating the water tolerance of any mixture of petrol with ethyl alcohol from critical solution temperature measurements on a few mixtures with the particular petrol. Conversely, it is also possible to compute critical solution temperatures of mixtures of known composition. The average deviation between observed and calculated critical solution temperatures of the 23 petrols studied, was 1.4° C.

Critical Solution Temperatures of Mixtures of Petrol, n-Propyl Alcohol and Water. (E. W. Aldrich, Bur. Stan. J. Res., Vol. 20, No. 1, Jan., 1938, pp. 9-16.) (53/36 U.S.A.)

Data are presented on the separation temperatures of mixtures of 5, 10, 15, 20 and 25 per cent. of *n*-propyl alcohol of various water contents with each of three petrols. These data are compared with similar data on mixtures of petrol with ethyl alcohol, and it is shown that the water tolerances of mixtures of petrol with *n*-propyl alcohol are, in general, greater than those of corresponding mixtures with ethyl alcohol.

Lowering the Ignition Temperature of Gas Oils. (Autom. Ind., Vol. 78, No. 6, 5/2/38, p. 168.) (53/37 France.)

Although greatest reductions in ignition temperature are generally obtained by adding a substance of lower ignition temperature than that of the parent oil, there are several cases where an appreciable reduction of the ignition temperature of the mixture results, although the added substance alone has a higher ignition temperature than the gas oil. Thus the ignition temperature of castor oil and chloroform are of the order of at least 1,220° F. whilst that of gas oil is 1,115° F. Yet a 10 per cent. addition of castor oil causes a reduction of the ignition temperature of the mixture to 935°F., whilst a 10 per cent. addition of chloroform reduces it to 824° F. The ignition temperature of a mixture can thus not be predicted from those of its constituents.

Effect of Test Conditions on Fuel Rating. (A. E. Becker, J.S.A.E., Vol. 42, No. 2, Feb., 1938, pp. 63-72.) (53/38 U.S.A.)

The work planned by the Co-operative Fuel Research Committee, in 1936, had the object of studying C.F.R. engine variables on the knock rating of fuels. It was intended to develop separate test conditions:—

(1) Giving a rating, intermediate between the motor and research method.
(2) More severe than the motor method.
(3) Less severe than the research method.

This programme necessitated:—

(1) Standardisation of knock intensity.
(2) Determination of relationship between spark advance-power and spark advance-knock at several speeds and mixture temperature.

Broadly speaking, as regards their reaction to engine variables, fuel can be divided into sensitive, non-sensitive and intermediate fuels.

In the case of sensitive fuels, the combined effect of high speed and high temperature, materially reduces the rating. Advancing the spark increases the rating slightly at high speeds and temperatures and reduces it at low speeds and temperatures. In the case of non-sensitive fuels, there exist a large number of combinations of speed, temperature and spark advance, giving approximately the same rating.

From this, it appears that correlation between road and laboratory tests, is not a simple problem. It is hoped, however, that the data given in the report will lead to the defining of a new laboratory procedure, which will be a material improvement on the present method of rating.

Combustible Substances Considered as Promoters of Incombustible Extinguishers for the Practical Extinction of Flames. (C. Dufraisse and J. le Bras, Comp. Rend., Vol. 205, 1937, pp. 562-5. J. Soc. Chem. Ind. (Abstracts B), Vol. 57, No. 2, Feb., 1938, p. 125.) (53/39 France.)

The conditions under which a combustible vapour may promote the action of an incombustible extinguisher are discussed with reference to the ignition limits of the combustible vapour in air. Such a mixture may be particularly effective with flames which normally resist extinguishers.

Technical Gas Analysis by Measurement of Thermal Conductivity. (K. Andress, Gas-u Wasserfach., Vol. 80, 1937, pp. 922-5. J. Soc. Chem. Ind. (Abstracts B), Vol. 57, No. 2, Feb., 1938, p. 125.) (53/40 Germany.)

The electrical conductivity of a hot wire surrounded by a gas mixture is affected by (*a*) the thermal conductivity of the gases and (*b*) the heat of any reaction (*e.g.*, combustion) catalysed by the wire. Either effect may be made a basis for indicating, measuring, or recording, in suitable cases, changes in the composition of the gas mixture. The applicability of the method is discussed generally and suitable apparatus described. The accuracy depends on the nature of the measurement to be made. A list of technical applications is given.

Changes in Aero Engine Oils in Use and Methods of Testing Them. (v. Philippovitch, Oel. u Kohle, Vol. 13, 1937, pp. 1235-45. J. Soc. Chem. Ind. (Abstracts B), Vol. 57, No. 2, Feb., 1938, pp. 131-2.) (53/41 Germany.)

The results of research on ring sticking, the composition of C deposits, suspended C, sludge, and asphalt solubility in oils are summarised. The volatility of oils, coking tests, and a comparison of the results and criticism of the conditions of the various oxidation tests are dealt with. The German (D.V.L.) test is described and an apparatus illustrated which enables a rapid (8-hour) oxidation of oil at 198° in the finely divided state to be carried out, asphalt content being the criterion of stability. Experiments on ring sticking and C formation in (1) a small test engine, (2) large single-cylinder, and (3) complete aero engine are described and comparisons are drawn between the behaviour of oils in laboratory tests and in these engines. Tests were continued until ring sticking (indicated by loss of power, " blow-by," or rise in mean combustion space temp.) occurred. Good correlation was obtained between the small test engine and the large single cylinder aero engine as regards time to ring sticking.

In the case of natural and compounded oils, this time appears to be related to the asphalt content of the residual oil. Synthetic or reclaimed oils show no connection.

The Ageing of Lubricating Oils—Review of Recent Work. (G. R. Schultze, Z.V.D.I., Vol. 82. No. 8, 19/2/38, pp. 210-1.) (53/42 Germany.)

The ageing process of lubricating oil is accompanied by oxidation, condensation and destruction of the oil molecule.

Oxidation is catalytically accelerated by the presence of certain metals (especially copper and silver). Condensation takes place at higher temperature and is accompanied by an increase in the size of the molecule and the formation of ring compounds (increase of viscosity and production of asphalts). Destruction usually requires temperatures of the order of 200°C., but may take place at much lower temperatures in the presence of certain catalysts. It generally leads to an appreciable reduction in the flash point of the oil and is accompanied by the formation of acids and gums. Recently there has been a considerable increase

in the knowledge of the chemistry of gums and asphaltic compounds which has enabled a closer separation of the ageing products and a finer differentiation between various oils. The old method of separating gums by their solubility in benzene is quite useless and gives no criterion of the ageing process. From a review of experimental results, it is concluded that the ageing difficulties can be met by—

1. The use of synthetic oils rich in hydrogen.
2. Avoidance of oil mixtures from different sources.
3. The use of efficient filters.
4. The use of a laboratory test which subjects the oil to practical working conditions.

Effect of Altitude on Anti-Knock Requirements of Cars. (N. MacCoull, K. L. Hollister and R. C. Crone, Oil and Gas Journal, Vol. 36, No. 26, pp. 130, 133-4 and 137; Refiner Natural Gasoline Mfr., 16, pp. 534-41, 1937. Chem. Absts., Vol. 32, No. 3, 10/2/38, p. 1082.) (53/43 U.S.A.)

The octane number of petrol required by cars to suppress knock decreases with increasing altitude. The rate of decrease varies from 3 units per 1,000ft. elevation at sea level to about 7.5 units at 12,000ft. Average cars at elevations above 4,000ft. can use petrols of approximately 10 octane number lower than at sea level. Mixture ratios of average cars become too rich at high altitudes. The difference in octane number of cracked fuels obtained in road tests and by the A.S.T.M. method varied from +6 to −1.5 octane number. The anti-knock requirement with altitude was slightly less with cracked than with straight petrol, owing to the depreciating effect of altitude. At sea level the requirements for the cracked series averaged 1.5 lower than for straight run and at 6,000ft. they were one point higher.

Self-Lubricating Materials. (British Patent Nos. 470,449 and 471,734.) (Franz Sattler, Chem. Absts., Vol. 32, No. 4, 20/2/38, p. 1444.) (53/44 U.S.A.)

The proposed bearing is obtained by melting the metal or alloy (*e.g.*, Pb, Ni, Cu, bearing metal, bronze), with a considerable percentage, preferably 10 per cent. or more, of carbon particles, *e.g.*, graphite lamp black of colloidal size, by means of electric induction, a uniform distribution of the carbon being thus obtained. If the mass is allowed to cool under pressure, the product is non-porous and a supplementary lubricant is unnecessary.

U.S. Navy Correlation of Laboratory Tests on Diesel Fuels with Service Engine Operation. (W. F. Joachim, Trans. A.S.M.E., Vol. 60, No. 2, Feb., 1938, pp. 137-44.) (53/45 U.S.A.)

The Diesel fuel investigation at the U.S. Naval Engineering Experiment Station, authorised by the Bureau of Engineering in 1934, has included long-time storage tests, injection pump tests at low temperatures, cold-starting tests, physical-chemical analyses, ignition quality tests on the Co-operative Fuel Research engine, and combustion shock, power and economy, carbonisation, exhaust smoke, and miscellaneous fuel performance tests on several service Diesel engines. This paper presents a brief review of some of the work done in correlating the results of the physical-chemical analyses and ignition quality tests on the Co-operative Fuel Research engine with fuel performance in service engines.

Lubricating Problems in Connection with High Speed Diesel Engines. (C. G. A. Rosen, Trans. A.S.M.E., Vol. 60, No. 2, Feb., 1938, pp. 145-51.) (53/46 U.S.A.)

To a considerable extent the problem of lubrication connected with high-speed Diesel engines involves a study of the cause and effect of carbon and binder-forming depositions. The following points are considered:—(1) Influence of carbon and binder forming depositions on ring sticking, valve sticking, and lubricating oil filter; (2) cylinder and ring scratching; and (3) bearings.

The influence of fuels and the combustion process is considered as distinct from the effect of piston ring belt temperatures.

The importance of co-operative research of engine manufacturers with the petroleum industry is emphasised.

Determination of Oxygen Content of Exhaust Gases by the Thermal Conductivity Method. (K. Andress, Archiv für Wärmewirtschaft, Vol. 19, No. 2, February, 1938, p. 32.) (53/47 Germany.)

The thermal conductivity method of exhaust gas analysis, whilst being very suitable for CO_2 determination, breaks down when O_2 is to be determined, since the difference in conductivity is too small. In the modification of the apparatus proposed by the author, the exhaust is mixed with a known proportion of H_2 and its relative thermal conductivity determined. The mixture then enters a catalytic combustion tube and, after the removal of the steam produced, the relative thermal conductivity of the mixture is determined a second time. The oxygen content is thus obtained by difference and the author claims satisfactory accuracy, provided the gas flow is uniform and the rate of admixture of the hydrogen is constant.

Detonation and Auto-Ignition. Some Considerations on Methods of Determination. (G. D. Boerlage, Journees Techniques Internationales de l'Aeronautique, 23-27, November, 1936, pp. 1-22. Available as Translation T.M. 843.) (53/48 Holland.)

The author is of the opinion that the so-called " detonating " combustion in a spark ignition engine is identical with the " auto-ignition " taking place normally in a Diesel engine. As we wish to avoid detonation in the one case and promote auto-ignition in the other, high octane numbers should correspond to low cetane numbers and vice-versa, and a general relationship of this type has indeed been demonstrated by the author.

A brief review of the various methods at present in use for rating fuels is given. Besides the difficulty of getting consistent results by any given method (a difficulty which increases considerably for fuels of high octane rating) there is the further difficulty of obtaining agreement with full-scale results, since the laboratory engine used for rating purposes necessarily presents a compromise and may not represent essential full-scale conditions. It appears that these difficulties will only be overcome if the nature of the essential factors determining detonation become more fully known, and considerable further research will be necessary to achieve this.

Flight Testing with an Engine Torque Indicator. (A. L. MacClain and R. S. Buck, J.S.A.E., Vol. 42, No. 2, Feb., 1938, pp. 49-62.) (53/49 U.S.A.)

A torque indicator, in which the reaction forces of the fixed gear in the propeller reduction gearing are measured, has been developed and flight tested by Pratt and Whitney.

In this device, the reaction forces are balanced by oil pressure acting on two pistons, the required pressure being recorded on an ordinary pressure gauge in the cockpit. Using a constant speed propeller, it has been possible to make complete engine calibrations of power versus manifold pressures at various engine speeds at several altitudes between sea level and 20,000 feet. The added weight is about 20lb.

Fuel consumptions, induction system temperatures and pressures at several points from the carburettor inlet to the intake port, cylinder temperatures, aeroplane speeds, miles per gallon, and other data were obtained in flight. The effect of mixture strength on power, aeroplane speed, cruising range and on general engine operation has been evaluated. The differences in air speed and engine power between an uncowled engine with short exhaust stacks and the same engine with cowling and collector are shown. Very illuminating results are

shown as to the effects of cowl flap opening on engine power, aeroplane speed, drag coefficient, and fuel consumption in miles per gallon.

Type of Flow in Gas Measuring Nozzles. (F. Kretzschmer, Forschung, Vol. 9, No. 1, Jan.-Feb., 1938, pp. 35-40.) (53/50 Germany.)

Present day measuring nozzles have a cylindrical exit and the author shows that under these conditions the retardation at the boundary produces periodic changes in the type of flow. The exit section is thus not always filled by the gas stream and this leads to changes in the effective discharge coefficient. For this reason the author favours the sharp-edged orifice method for metering air in which the type of flow is more consistent.

The N.A.C.A. Optical Engine Indicator. (R. E. Tozier, N.A.C.A. Tech. Note No. 634, January, 1938.) (53/51 U.S.A.)

An optically recording engine pressure indicator of simple and rugged construction has been developed for use in high pressure and high temperature combustion research. This instrument is of the diaphragm type and has a natural frequency of about 10,000 cycles per second.

A Method of Harmonic Analysis. A Study of the Rotational Frequencies of Screw Propellers, (G. F. Partridge, Phil. Mag., Vol. 25, No. 168, March, 1938, pp. 505-39.) (53/52 Great Britain.)

A method of harmonic analysis of the dynamometer type is described. A string electrometer is employed, the e.m.f. to be analysed being applied to the string, while an analysing e.m.f. of variable frequency is applied to the plates. The frequency of this analysing e.m.f. is varied continuously, and the ensuing deflections of the string, corresponding to the various component frequencies of the e.m.f. under examination, are recorded photographically. In this way an automatic frequency calibration of the record is obtained, and the amplitudes of the various components can be measured directly from the record without the necessity for determining their phase differences.

The method of analysis is applied to various electric and acoustic problems, in particular to the analysis of a series of electrical impulses.

A general theoretical analysis for a series of impulses is given, and this is applied to the explanation of the results obtained on analysing the sounds of rotation from screw propellers.

Formulæ are derived for determining the constants of a string electrometer.

The Elastic Limit of Steels Undergoing Fatigue Tests and its Relation to Fatigue Limits, Internal Damping and Notch Sensitivity. (H. Buchner, Forschung, Vol. 9, No. 1, Jan.-Feb., 1938, pp. 14-27.) (53/53 Germany.)

The elastic limit was determined by temperature changes in the specimen, the occurrence of slip being accompanied by an appreciable generation of heat.

The elastic limit thus determined depends very markedly on the method of loading and pre-treatment of the specimen. If the specimen is subjected to longitudinal stress during the fatigue tests (torsion or bending) failure is accelerated.

The author has traced a definite relationship between the elastic limit and other factors such as fatigue strength, damping and notch sensitivity. In certain cases this leads to an accelerated method of testing which is simpler than the standard process.

Non-Shrinking Films for Aerial Photography. (A. Charron and S. Valette, Pub. Sci. et Tech., No. 146, 1937, pp. 1-101.) (53/54 France.)

Ordinary photographic films distort on developing, *i.e.*, a certain distance on the image at the moment of exposure (and which at that instant will correspond with the same distance on the ground glass screen) will not be the same after development and will undergo further changes on storing of the film. This

distortion is mainly due to the action of water on the film support (cellulose ester plastic fillers, etc.) and is the same whether an emulsion is present or not. The authors have investigated the action of water on the film support and have produced a cellulose tri acetate film (acetic acid content of the order of 60 per cent.) which, when mixed with suitable fillers and solvents (*e.g.*, 30 per cent. of triphenyl phosphate), is perfectly stable under the action of water, provided it is subjected to a preliminary heat treatment (four hours at 100°C.). Adaptation of the process to commercial manufacture of this type of film is described as well as the production of single plates of this material.

The Theory of the Photolysis of Silver Bromide and the Photographic Latent Energy. (R. W. Gurney and N. F. Mott, Proc. Roy. Soc., Series A, Vol. 164, No. 917, 21/1/38. pp. 151-166.) (53/55 Great Britain.)

An attempt is made to explain the photolysis of silver halides in terms of the concepts of atomic physics. The mechanism by which the silver atoms formed by the light coagulate to form specks of metallic silver is discussed. The ideas used in this discussion are then turned to the photographic latent image, and are shown to account qualitatively for the variation of developed density with temperature, and, for given exposure, with intensity of light. A brief discussion is given of the Herschel effect, and of sensitisation by dyes.

The Heat Conductivity of a Packing of Small Balls in a Quiescent Gas. (G. Kling, Forschung, Vol. 9, No. 1, Jan.-Feb., 1938, pp. 28-34.) (53/56 Germany.)

The packing filled the space between a central sphere (electrically heated) and a surrounding hollow sphere. The conductivity was deduced from surface temperature measurements of the spheres, the amount of heat energy supplied being known. The packing consisted of small steel balls (3.18 mm. diameter) which were arranged as closely as possible. Experiments were carried out with various gases (air, hydrogen, methane, propane, CO_2) at pressures ranging from a few mm. Hg to 50 atmospheres. At high pressures, the conductivity is practically independent of the pressure, but falls rapidly with reduced pressure if a certain critical pressure is passed. This behaviour is attributed to the effect of the boundary layer on the packing balls and a theoretical treatment of the pressure effect on these lines is in satisfactory agreement with the experiments.

Photothermometry. (P. Neubert, Archiv für Wärmewirtschaft, Vol. 19, No. 2, February, 1938, pp. 29-32.) (53/57 Germany.)

Recent development in red sensitised photographic plates has made it possible to photograph bodies by their own thermal radiations, the source being at as low a temperature as 275°C. At these lower limits the exposure times are of the order of several hours, but this time is reduced to a few minutes at 450°C. and to a fraction of a second at temperature above 600°C. The density of the photographic record is measured by means of a micro-photometer and the temperature estimated by comparison with the record obtained from a standard source of radiation maintained at a known temperature (Ni cylinder painted with cobalt oxide). It is claimed that temperature can be read to within 1°C., the true surface temperature being of the order of 400°C. The method is of special interest when investigating flow phenomena since the temperature field is not affected by the introduction of recording instruments. As an interesting example the photograph of a heated metal cylinder hanging vertically is reproduced which shows the production of vortices by the ascending convection currents.

On the Blocking Layer Photo-electric Effects of Caesium Oxide. (H. Teichmann, Phil. Mag., Vol. 25, No. 167, February, 1938, pp. 269-273.) (53/58 Germany.)

In a previous paper the author expressed the opinion that the intermediate layers of the composite cathodes of photo cells act as semi-conductors. In this

way the wave length of the light giving maximum external photo-electric effect could be predicted, being identical with the wave length for which the blocking layer photo-electric effect is a maximum.

The original experiments on K-Se cells have now been repeated with Ag-Caesium oxide cells and the results are in agreement with the author's theory.

The Application of Wireless to Aerial Navigation. (Journal des Telecommunications, Vol. 4, No. 11, Nov., 1937, pp. 301-307.) (53/59 France.)

In order to determine by means of wireless the position of an aircraft relative to a ground station, the following possibilities arise:—(1) The aircraft send out a symmetrical wave, the point of origin being estimated by the land station and telephoned back to the aircraft. (2) The land station sends out a symmetrical wave, the point of origin being estimated on the aircraft. (3) The land station sends out a rotary pencil of radiation together with reference signals (N/S and E/W). The aircraft estimates the bearing of the station from the known rate of rotation and the time interval between reference signals and zone of silence. (4) The land station sends out a fixed pencil of radiation and the aircraft follow this beacon (radio beacon). (5) The land station sends out a symmetrical wave. This is picked up on the aircraft using a frame aerial in continuous rotation. A galvanometer indicates the angle between the direction of travel of the aircraft and the direction of the station (radio compass). A recent development is presented by the radio course indicator of Santucie. This instrument uses a double rotating frame one of which operates like a radio compass whilst the second responds to the earth's magnetic force and gives the angle between the course of the aircraft and the magnetic meridian. By a suitable combination of the two frames, a constant reading on the indicator shows that the aircraft follows a given ground course. (The ordinary radio compass does not allow for drift.)

Relaxation Methods Applied to Engineering Problems. II—Basic Theory with Application to Surveying and to Electrical Networks and an Extension to Gyrostatic Systems. (A. N. Black and R. V. Southwell, Proc. Roy. Soc., Series A, Vol. 164, No. 919, 18/2/38, pp. 447-67.) (53/60 Great Britain.)

The " Method of Systematic Relaxation of Constraints " was devised for the determination of stresses in frameworks, that is in elastic structures having the characteristic that a strained configuration can be specified by attaching values to a *finite* number of co-ordinates. Recently it has been extended to continuous systems (*e.g.*, beams) on the understanding that a finite number of co-ordinates will define a configuration for practical purposes, though not from a mathematical standpoint. So far the power of the method has been exhibited only in relation to elastic problems; in these its results appear to converge rapidly, judged by a few examples of which the exact solutions were known.

The aim of the present paper is fourfold, viz.:—

(1) To prove that relaxation methods, applied systematically to problems of elastic equilibrium, give solutions which converge steadily towards exact results; and hence, by analogy,

(2) To show that they are applicable to any " minimal " problem, *e.g.*, the adjustment of errors according to the method of least squares.

(3) To notice, as particular examples, the adjustment of errors in level or triangulation surveys, and the partition of electric current in non-inductive networks of conductors; and

(4) To discuss the more difficult problem of an inductive network carrying alternating current. This serves as a simple illustration of systems which are governed by equations containing " gyrostatic " or " non-energetic " terms, and which for that reason do not present minimal problems of the usual kind.

REVIEWS.

HISTORY OF AERONAUTICS. A SELECTED LIST OF REFERENCES TO MATERIAL IN THE NEW YORK PUBLIC LIBRARY.

Compiled by William B. Gamble. The New York Public Library, New York, 1938. $2.00.

This new bibliography of the History of Aeronautics as exemplified by the material available in the New York Public Library is at once a testimonial to the aeronautical contents of that library and to the excellent work done by Mr. Gamble. There are no fewer than 5,574 references, not only to complete works, but to papers in periodicals and the like. For example, under the History of the Royal Aeronautical Society appears not only references to the Journal, but also to Mr. Hodgson's excellent survey which appeared in the Air Annual of the British Empire in 1929.

There is a first-class subject and author's index which adds greatly to the value of the bibliography which, in itself, is arranged conveniently in subjects. The volume deals only with references to the history of aeronautics and covers every side from heavier-than-air craft to air mail, from airships and balloons to war in the air. It is a volume which should be in every reference library.

G. OTTO: "ENTWURF UND BERECHNUNG VON FLUGZEUGEN, BAND II, RUMPF." (Design and Calculation of Aeroplanes, Vol. II, Fuselage). 96 pp., 103 figs. and many numerical tables. Published by C. J. E. Volckmann Nachf. E. Wette, Berlin-Charlottenburg, 1938. Price R.M. 3.50.

This second volume (see the Journal 1937, p. 1205) appears to give a fair treatment of the stressing of modern aeroplane fuselages. The calculation follows strictly the German load specifications, and the example given is based on a Heinkel He. 64 fuselage, representing a typical low-wing monoplane. Both built up girder frame structures and stressed skin shells are considered but the former seems to have been treated in a somewhat too abridged manner. A short chapter describes different methods of construction, the Vickers-Wallis geodetic formula, riveted tubular girder structures (Boulton & Paul), welded tubular structures and shell type fuselages.

The book can be recommended for those conversant with stress calculations and wishing to obtain information with regard to aeroplane fuselages.

FLUGTECHNISCHES HANDBUCH, Band IV (Handbook of Aeronautics, vol. IV). Edited by Dr.-Ing. Roland Eisenlohr, Berlin and Leipzig 1937. Published by W. de Gruyter & Co., 202 pp. with 100 figs. and tables. Price R.M. 7.50.

The first three volumes of this handbook were reviewed in the Journal of 1937, p. 862. The fourth volume covers meteorology and lighter-than-air craft; it also contains valuable numerical tables.

The chapter dealing with aeronautical meteorology is written by Prof. Kurt Wegener (Graz), a scientist with a long standing experience as a pilot of balloons, aeroplanes and sailplanes (well known over here by his daring balloon flights to and from England). The physics of the atmosphere is dealt with by Miehlnickel and weather forecasting by K. Schreiber. Free and captive balloons and their handling are treated by A. Dahl with special reference to stratosphere

balloons, and airships by W. E. Doerr, an old collaborator of Count Zeppelin, including an interesting historical survey. Other chapters cover navigational problems Wittemann, airship engines H. Butterweck, and airship stations A. Kolb.

Twenty-six numerical tables collected in this volume add valuable data for scientists, designers and pilots.

THE SCIENCE OF PETROLEUM. A COMPREHENSIVE TREATISE OF THE PRINCIPLES AND PRACTICE OF THE PRODUCTION, REFINING, TRANSPORT AND DISTRIBUTION OF MINERAL OIL.

Editors: A. E. Dunstan, D.Sc., London; A. W. Nash, M.Sc., Birmingham; B. T. Brooks, Ph.D., New York; Sir Henry Tizard, K.C.B., M.A., F.R.S., London. Published by the Oxford University Press, in Four Volumes. Price 15 gns.

When invited to review this work, the writer thought that it would be a lifetime's job. But on further consideration he decided that the individual articles, comprising four quarto volumes and totalling over 3,000 pages, could not be reviewed authoritatively by any one person, especially since each article is the work of a specialist on the particular subject. If one did this, it would be similar to criticising and reviewing the individual items contained in an encyclopædia. So he thought that it would be more helpful to give a comparatively short review; but it is quite obvious that those concerned with mineral oil and its many treatments and applications must have the four volumes of this work in their reference library. No library or organisation would be complete without it.

" The Science of Petroleum " has taken a long time to compile and its publication is a year or two late. In common with practically all technical publications, it has been said that the information contained in this work would be out of date before it was printed! But it is also quite true to say that in hardly any other industry, and in all its various aspects, have there been such tremendous advances in knowledge and technique as there have been in the oil industry during the last ten years or so—and these advances are still continuing to be made. It is therefore no slur upon a work of this kind to say that it is out of date when published. Obviously, it will be out of date in certain respects, but the fundamentals are there and it would be a very poor look out for the oil industry if it were up to date when published! Because this would mean that the technique in the treatment of mineral oil would not have advanced to any real extent and, literally, things would be at a standstill. The chemists and engineers in this great industry could then only regard themselves as " has beens."

The work is excellently printed and the illustrations, of which there are many, are reproduced very clearly; but this is only to be expected from the Oxford University Press.

It is safe to say that " The Science of Petroleum " is the most complete work which has yet been published on the oil industry. Over 300 authors of many nationalities and all specialists on their various subjects, have contributed some 400 articles, forming the four volumes of the work.

To give some idea of its scope, hereunder are the contents of the various volumes:—

Volume I.—Section 1, Nomenclature; 2, Statistics; 3, Origin; 4, Distribution; 5, Migration; 6, Natural Accumulations; 7, Geological Methods of Exploration; 8, Geophysical Methods of Exploration; 9, Methods of Drilling; 10, Sampling, Coring and Borehole Surveying; 11, Production; 12, Oilfield Waters; 13, Power in Oilfield Development; 14, Measurement of Oil, Gas and Water in Oilfields; 15, Crude Oil Transport; 16, Natural Gas Transport; and 17, Storage of Oil and Gas.

Volume II.—Section 18, Nature of Crude Petroleum; 19, Chemistry of Petroleum; 20, Physical and Chemical Properties of Petroleum and Its Products—Determination, Correlation and Collected Data; 21, General Analysis and Testing; 22, History and Development of Refining; 23, Casing-Head Gasoline Extraction; 24, Natural and Refinery Gases; and 25, Distillation.

Volume III.—Section 26, Refinery Processes, Physical; 27, Refinery Processes, Chemical; 28, Solvent Extraction Refining; 29, De-Waxing; 30, Gas Pyrolysis and Polymerisation; 31, Cracking; 32, Hydrogenation; 33, Engineering and Chemical Engineering as Applied to Refining; 34, Metals and Alloys in Refinery Equipment; 35, Corrosion; 36, Instruments and Meters; 37, Electrification of Refineries; 38, Power and Water Supplies; and 39, Fires.

Volume IV.—Section 40, Products of Petroleum; 41, Combustion; 42, Deterioration; 43, Oil Shales, Torbanites, Cannels, etc.; 44, Shale Oils and Tar Oils.

Complete indexes of contributors' names and subjects are given and, whilst some may criticise the references given by the authors at the end of their articles on the score that some work or other has been omitted, it must be remembered that each subject treated is a work in itself and, probably, the information on it, in the form of papers, etc., so vast, that it would be almost impossible, and even confusing, if each author were to remember and give a reference to every paper or utterance that had been made on the subject over, say, the past ten years.

The writer can criticise one point regarding the make-up of this work, and that particularly concerns the references at the end of each article. These are arranged alphabetically and are numbered consecutively according to their alphabetical arrangement. But, if one refers to the index of names at the end of Volume IV, against the particular name one is looking for, one is given the page numbers of the article or articles in which this name is referred to. One then turns to these page numbers and finds that the person's name is on the list of references but, because the names are arranged alphabetically and the numbers against each name are consecutive, it means that one has practically to read through the article in order to find out where the numbered reference occurs.

P. A. Fischer von Poturzyn: "Luftmacht" (Air Power). Present and Future of Air Power as seen abroad. With collaboration of E. Billeb. 176 pp. with 35 figs., 30 tables and maps. Published by Verlag Kurt Vowinckel. Heidelberg-Berlin 1938. R.M. 5.80.

The author, for many years connected with Junkers for publicity purposes, endeavours to give in this book a complete survey of the different opinions about air power held in countries outside Germany. He considers the air force to be the deciding factor in war and compares the different forms of organisation and sizes (apparently with an intended exaggeration of the Russian air armament). His conclusions seem often somewhat fantastic as the following translated sentence may prove to a reader outside Germany:

". . . Therefore, the development of aeronautics has, so to speak, historically caused the formation of autoritative Governments among those nations which consider themselves young ones and which believe in a greater future . . ." (p. 25).

The reader will find more of this sort of philosophical mysticism which replaces logical conclusions by mere verbal effort and which has become so important for the philosophy of modern Germany. The author writes good "journalese" of this kind of "autoritative" outlook, but his judgments are too often not well founded or not founded at all.

His personal observations of the air operations in Abyssinia and Spain are interesting (the author is a former naval officer) and full of valuable details, but it does not seem fair to draw fundamental conclusions from these operations for any major conflict between well-armed nations. It would certainly be as misleading as a comparison of the Tripoli war of 1912 and the Balkan war of 1913, with the operations of 1914-18.

The same objection applies to his survey of modern technique in air armament wherein he confuses serious development work with rather abstruse inventions which will be considered pure nonsense by every military expert in aviation.

The strategics of air warfare culminate for the author in Douhet's doctrine of the absolute air warfare (the French Commandant M. Jauneaud should have been mentioned as well). The ideal basis of the British air strategy is—according to the author—Golovine's development of Douhet's doctrine and is claimed to be officially accepted as such.

The importance of meteorology which still, to-day, governs all air operations, seems to be entirely overlooked by the author.

Curiously enough, the valuable book of H. Ritter as an acute predecessor of this book is not mentioned at all, in spite of its influence upon aircraft the author's firm has constructed and sold abroad.

The remaining chapters refer to commercial aviation. Excellent pictures and graphs assist the book which is, at any rate, readable.

FIGHTING PLANES OF THE WORLD.
Edited by Commander E. C. Talbot-Booth, R.N.R. Compiled by E. Sargent. Sampson Low, Marston and Co., Ltd. 7/6 net.

This is an excellent little reference book, containing much information not available except in scattered sources. The first chapters are devoted to a useful history of the Royal Air Force, its commands, squadron histories, entry and training, the Royal Air Force Volunteer Reserve, Auxiliary Air Force and Fleet Air Arm. The last chapter was written before the recent change over to the Admiralty and the next edition will be in the nature of history.

A chapter is devoted to the various types of fighting aircraft and a brief survey of their uses, and one on airships. The remainder of the volume deals with the principal fighting aircraft of the chief countries of the world, giving all such particulars as are immediately available.

There are many excellent illustrations, particularly those in colour of the international markings of aircraft, rank markings and flags, badges and representative squadron units.

" Fighting Planes of the World " can be thoroughly recommended.

The 626th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, Westminster, London, S.W.1, on Thursday, November 18th, 1937, at which a paper on "The Effect of Wing Loading on the Design of Modern Aircraft, with Particular Regard to the Take-off Problem," by Mr. H. F. Vessey, B.Sc., A.F.R.Ae.S., was presented and discussed. In the chair: Mr. A. H. R. Fedden, Vice-President.

The CHAIRMAN: Mr. Vessey had graduated with honours at London University. After spending some time in industry he had joined the Air Ministry about eight years ago and was now on the Directorate of Scientific Research. Thus he had had both practical and research experience.

THE EFFECT OF WING LOADING ON THE DESIGN OF MODERN AIRCRAFT WITH PARTICULAR REGARD TO THE TAKE-OFF PROBLEM.

By H. F. VESSEY, B.Sc., A.F.R.Ae.S.

The author wishes to express his appreciation of the honour that has been paid him in being requested to present a paper before the Royal Aeronautical Society. Permission has been given by the Air Ministry for the publication of the paper, but the author is alone responsible for the views expressed.

1. INTRODUCTION.

In attempting to trace the effect of wing loading on the design of modern aircraft the number of variables is extremely large and many of the factors warrant a paper in themselves. Thus the following treatment can only be a brief statement of the general effects and the omissions must be many. An attempt has been made to reduce the problem to its simplest terms so that the effect of the main variables may be clearly shown. The paper may be considered as divided into two main portions, the first dealing with the effect of wing loading on performance and the second discussing the problem of landing and take-off at the present wing loading and at the higher wing loadings which may be expected in the future.

2. OPTIMUM WING LOADING.

In clean modern aircraft the drag consists mainly of skin friction and induced drag, but in addition we must at present face extra drag due to engine cooling, wing-body and wing-nacelle interference and the minor excrescences caused by the necessity for giving pilots and crew a good flying view. By reducing the wing area geometrically the surface drag will be decreased, but the induced drag will be increased. At low wing loadings and fairly high speeds the induced drag is negligible, but as the wing loading is increased the induced drag becomes more important, and eventually a point will be reached where the total drag is a minimum and any further decrease in area will give a larger increase in induced drag than the consequent reduction in surface drag. This point will occur at comparatively high wing loading for modern aircraft and will vary with power, cleanness, induced drag coefficient, wing profile drag coefficient and height of operation. For any aircraft cruising at a given power and altitude there will

be one wing loading which will give a maximum speed and therefore minimum fuel for a specified range. This wing loading being the one at which the wing developes its maximum lift/drag ratio at the given cruising condition.

It can be shown (see Appendix I) that this optimum loading is given by

$$w = \tfrac{1}{2}\rho_0 \sigma V^2 \sqrt{(a/b)} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where V is the optimum speed defined by the cubic equation

$$550\,\eta/\lambda = P\sigma V^3/100^2\,W + 2\,V\sqrt{(ab)} \quad . \quad . \quad . \quad (2)$$

where w = optimum wing loading, lb. per sq. ft.
V = optimum speed, ft. per sec.
σ = relative density.
λ = power loading, lb. per h.p.
a = wing profile drag coefficient.
b = wing induced drag coefficient.
η = airscrew efficiency.
P = " extra to wing " parasite drag lb. at 100ft. per sec.
W = all-up weight, lb.

Let us consider two typical aeroplanes, one a reasonably clean biplane several years old and the other a clean monoplane representative of modern practice, and determine the optimum speed and wing loading for each.

In the table below columns 1-5 define the characteristics of the aircraft flying at ground level. Columns 6 and 7 give the existing speed and wing loading, while columns 8 and 9 show the maximum speed which can be obtained by reducing the wing area geometrically and the wing loading for that speed.

Aircraft	η	λ	P/W	a	b	Actual speed m.p.h.	Actual w	Optimum speed m.p.h.	Optimum w
Typical Biplane	0.77	9.74	0.05	0.010	0.07	127.5	10.3	128.8	15.9
Clean modern Monoplane	0.82	10.7	0.0052	0.0075	0.055	232	18	255	62

It will be seen that the old type biplane has a performance which is very close to the optimum, but that the performance of the cleaner aircraft could be appreciably improved by reducing the wing area. The reason that the existing wing area is not higher is of course that the difficulty of take-off and landing increases rapidly with wing loading.

The case of this modern aircraft merits further attention, and Figs. 1-3 have been prepared to show the effects of the main variables. Fig. 1 shows the effect on speed of reducing the wing area. It will be seen that the increase of speed is rapid at first, but that the curve becomes flatter as the optimum wing loading is approached. Thus if take-off and landing are difficult a speed near the optimum can be obtained at a wing loading considerably lower than optimum. On the other hand, if these difficulties can be overcome an appreciable gain in structure weight is obtained by reducing the wing area to give a wing loading greater than optimum. This is particularly noticeable in the consideration of long range aircraft where a wing loading considerably greater than optimum may be economic by reason of the reduction in structure weight and the greater load of fuel that can therefore be carried for a given all-up weight, this increase in fuel more than compensating for the slight reduction in cruising speed.

Fig. 2 shows the effect of power loading on the optimum wing loading and speed. The speed is increased by a reduction in power loading (increase in power), and the increased speed reduces the effect of induced drag, postponing the point at which the increase in reduced drag equals the reduction in surface drag, and therefore increasing the optimum wing loading.

Fig. 3 shows the effect of altitude and aspect ratio on the optimum speed and wing loading for constant power at any altitude. Increase in altitude and decrease in aspect ratio both have the effect of increasing the induced drag and so decreasing the optimum wing loading. The effect of aspect ratio on speed at ground level is comparatively small, but increases with height, and at

30,000 feet, which is approximately the altitude proposed for so-called stratosphere flight, aspect ratio becomes an important factor. There are two effects of increased aspect ratio which are not shown in this graph; these are the increase in structure weight and the decrease in interference drag. The second of these effects is extremely difficult to estimate, but is thought to be an important factor. As the aspect ratio is increased the wing area affected by wing-body and wing-

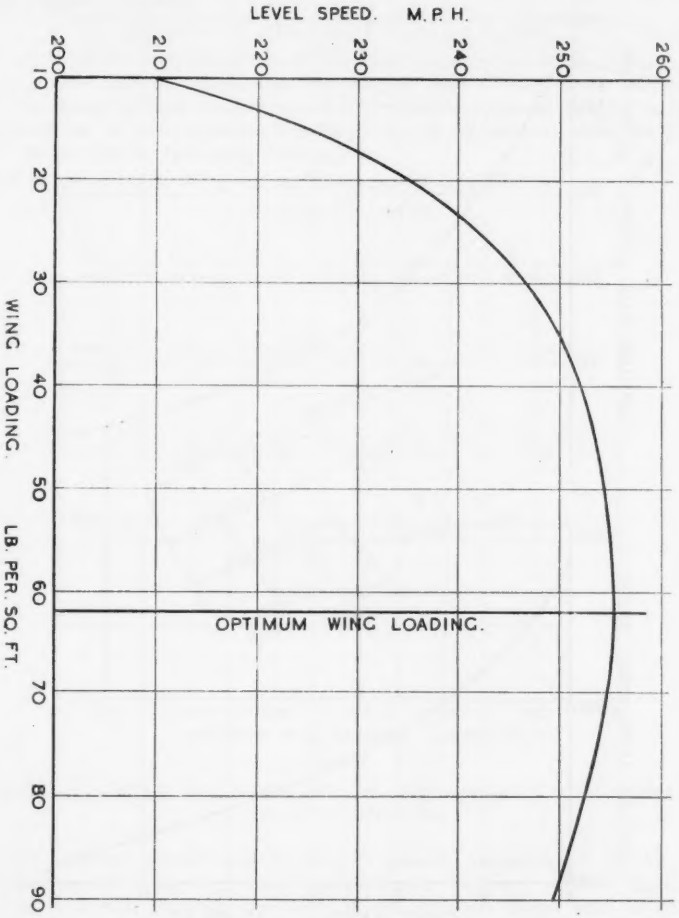


FIG. 1.

Effect of wing loading on cruising speed.

nacelle interference and by slipstream drag is decreased. At present even in very clean designs this interference drag must be faced, and the tendency to higher wing loadings increases the percentage of wing area that is "spoiled" by these interferences. Thus the effect of aspect ratio shown in Fig. 3 may be considered to be underestimated. The final choice of aspect ratio for any design must be a compromise between the aerodynamic advantages of high aspect ratio and the structural advantages of low aspect ratio. It is evident

that there is some difference of opinion on this point between designers as we find a variation of aspect ratio from under six to almost ten in aircraft designed for similar duties.

It will be seen that although an increase in aspect ratio at ground level has little effect on speed it considerably increases the optimum wing loading. This means that the higher the aspect ratio the smaller will be the wing area for

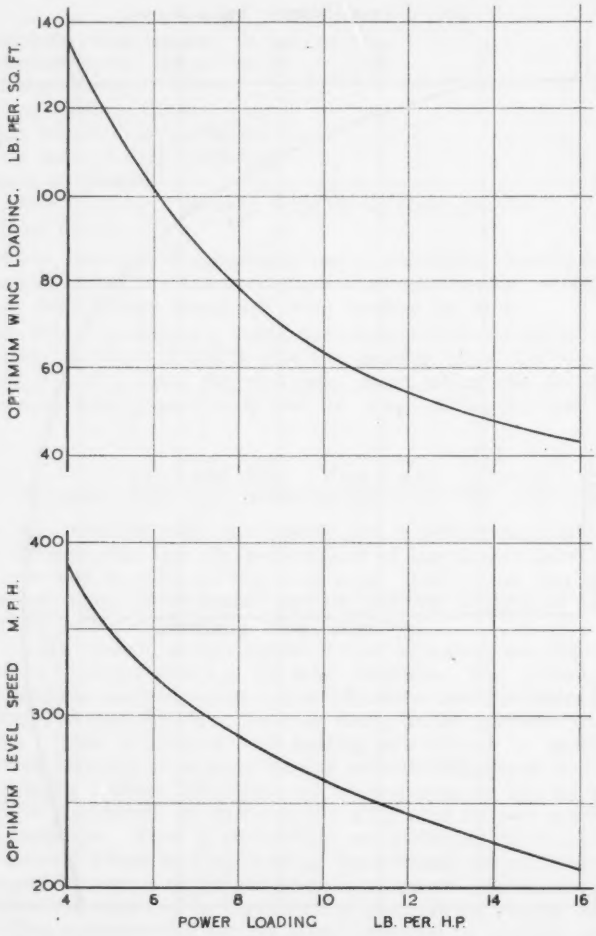


FIG. 2.

Effect of power loading on optimum speed and wing loading.

optimum conditions, so that the increase in weight due to the increased aspect ratio will be partly off-set by the decrease in area.

The dotted series of curves in Fig. 3 have been included to show the effect of halving the parasite drag. The increase in speed and in optimum wing loading is considerable, but the curves are of the same general type and show the greater effect of aspect ratio at altitude. As the optimum wing loading is approached the effect of parasite is increased as it is then a larger proportion of the total

drag. In this condition, therefore, it becomes all the more necessary to reduce parasite drag to the absolute minimum.

Before leaving the subject of optimum loading it will be of interest to consider the academic case of the streamline flying wing. Here the total drag consists merely of wing profile drag and induced drag. As the extra-to-wing parasite drag is zero the term containing P in equation (2) vanishes so that we are left with the simple expression

$$550\ \eta/\lambda = 2\ V\sqrt{(ab)} \quad \text{or} \quad V = 550\ \eta/2\ \lambda\sqrt{(ab)}. \quad . \quad . \quad . \quad (3)$$

Thus we have the surprising result that the optimum speed is directly proportional to power and is independent of height, and therefore no advantage is obtained by flying at high altitudes even if ground level power can be maintained. The explanation of this apparent contradiction of all present ideas on " stratosphere " flight lies in the wing loading.

As before the wing loading for optimum speed is given by

$$w = \tfrac{1}{2}\ \rho_0 \sigma V^2 \sqrt{(a/b)}.$$

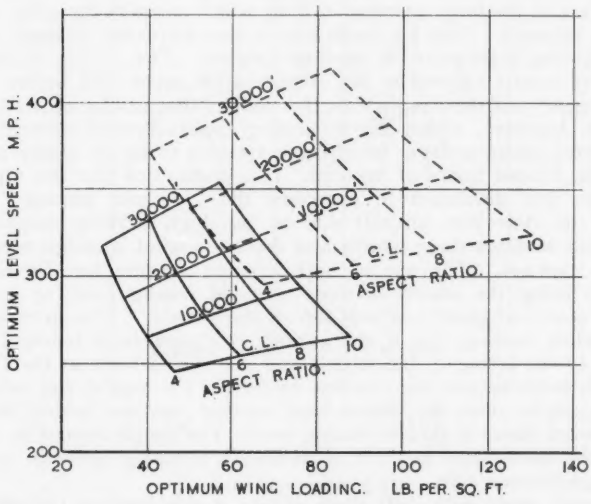


FIG. 3.

Effect of altitude and aspect ratio on optimum speed for constant power at all altitudes.

Thus for constant speed wing loading is directly proportional to the relative density, and so the wing area must be increased for high altitude flight. This increase in area will increase the surface and induced drags and so offset the decrease in drag due to density.

This case is of only academic interest as the wing loadings involved are enormous, being of the order of 500 to 1,000 lbs. per square foot, and the speeds obtained by this treatment are fictitious as they considerably exceed the speed of sound. In addition, a flying wing must carry all the load in the supporting surfaces so that with the very high loadings necessary for optimum conditions the wing area will be small and the stowage space inadequate. It would then be necessary to increase the wing area to obtain stowage space and the wing loading would be lower than optimum at ground level, and a gain in speed would be obtained by flying at high altitudes where the wing loading would be nearer to optimum.

From the foregoing treatment it will be seen that even though we cannot at present expect to build the optimum flying wing, much higher wing loadings than are now in use would be advantageous both from the point of view of structure weight and of performance. The tendency to cleaner and higher-powered aircraft increases the wing loading required for optimum speed, and it may be expected that wing loadings of the order of 60 lb. per sq. ft., or even higher, will be used in the future if the disadvantages attendant upon this considerable increase over present values can be overcome. The chief of the factors limiting wing loading are take-off, landing, initial rate of climb, ceiling and in multi-engined aircraft flight with one or more engines not running.

Take-off wil be treated later, but a few preliminary notes on the other limitations will not be out of place.

3. LANDING.

The landing of clean aircraft requires special consideration, particularly when the wing loading is increased above 20 lbs. per sq. ft. The development of flap has made possible the use of relatively high wing loadings on clean monoplane types by virtue of the large increase in drag which steepens the glide and reduces the floating distance. The lift coefficient is also increased (though not proportionately), giving a reduction in landing distance. The subject of landing flaps has been very clearly treated by Mr. Alston in his paper read before the Society three years ago,* and there is little on this subject that can be added. One recent development, however, which affects landing merits special attention. This is the nose wheel undercarriage, which now appears to be so widely used in new designs in the United States of America. It is understood that this type of undercarriage was first developed to overcome the "ground looping" tendencies experienced on American aircraft due to the high braking torques, forward position of the undercarriage wheels and the cross wind landings necessitated by the use of runways. The use of high braking torques has forced American designers to bring the wheels forward to avoid nosing over, so that in many aircraft the centre of gravity is well behind the wheels. This in turn introduces instability when landing, for if the aircraft is yawed as it touches the ground the friction forces acting at the wheels and the inertia force at the C.G. form a couple which tends to yaw the machine further. The logical way of overcoming this difficulty is to move the wheels back so that they are behind the C.G. and to use a forward wheel to prevent nosing over. The couple formed by the braking forces and the inertia load at the C.G. is then a restoring moment, so that cross wind landings become safe.

If an aircraft lands with drift there will be a side load on the wheels which, with the inertia load at the C.G., will form a couple tending to yaw the aircraft. The effect of such a yaw when landing is shown in an exaggerated form in Fig. 4. At the moment of touching the aircraft is assumed to be level laterally, so that the braking forces on each wheel will be equal and can be represented by a force F acting at the centre line of the aircraft. Due to the deceleration there will be an inertia force P acting at the centre of gravity which, with F, forms a couple which in the normal aircraft, Fig. 4 (a), is an unstable one. This couple tends to yaw the machine further, and in fact will do so unless the pilot has sufficient control to counteract it or until the centrifugal force caused by the swing transfers load from the inner to the outer wheel. The condition is a dangerously unstable one and considerable trouble has been experienced in America from this cause. Attempts have been made to overcome the difficulty by locking the castoring tail wheel in the central position, and this has, to a certain extent, been successful, but the danger of tyre failure or structural damage due to the large side loads on the tail wheel is considerable. It may seem surprising that we in this country have not experienced similar difficulties, but the reason is that in general cross

* Journal of the Royal Aeronautical Society, August, 1935.

wind landings are not necessary with large aircraft as we are not restricted to the three or four paths of a runway system. In addition, we have not yet been forced to the high brake loads that are used in America, so that the wheels are not placed so far in front of the centre of gravity as in American practice. The danger is there, however, and will increase with further developments unless there is some alteration to the present type of undercarriage.

Fig. 4 (b) shows the effect of the nose wheel undercarriage, and it will be seen that the couple formed by the braking loads and the inertia force is a stable one, tending to reduce the angle of yaw.

Although this removal of instability at landing appears to be the main reason for the adoption of the nose wheel undercarriage in America, there are a number of other advantages which contribute largely to its attractiveness. Chief of these is the influence on landing distance, which does not appear to be confined to the larger brake torques that can be used. As visualised by the author, the technique of landing in a restricted area will be as follows. The aircraft will be brought in over the barrier at a speed as near the stall as is considered to be safe by the

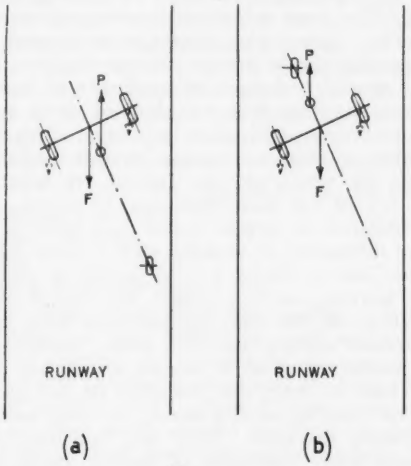


FIG. 4.
Landing with yaw.

pilot (say, 5 to 10 per cent. above stalling speed) and the glide will be continued down to the ground in a so-called " crash landing." As the machine touches the ground it will nose forward, due to the forward position of the centre of gravity, and the effect on the downwash striking the tail plane, which in the normal type of aircraft makes it so difficult to lower the tail for a three-point landing. As the machine drops on to the front wheel the wing incidence will be reduced to substantially zero, so eliminating " float " and putting the full weight of the aircraft on to the wheels. There will therefore be three factors tending to reduce the landing distance:—

(i) A lower gliding speed as excess velocity is not required to rotate the aircraft when touching down.

(ii) The complete suppression of the " flatten out and floating distances " which are so considerable in modern machines.

(iii) The removal of the lift directly the machine touches down, so allowing the full braking force to be applied over the whole of the ground run. This braking force can also be higher than normal as there is no danger of nosing over.

This type of landing will involve a considerable increase over present rates of vertical descent when touching down. An increase in the energy absorption of the undercarriage will therefore be required and because of this a more normal landing will probably be used except in special types, but even in this case the saving in distance should be considerable. The procedure would then be a glide at, say, 10 to 20 per cent. above the stall followed by flattening out. The saving in distance will then be due to the higher braking force acting over the whole of the run.

It should be noted that a " bounce " when touching down at a high speed is much less dangerous than in conventional types, as due to the C.G. being in front of the wheels the wing incidence will be decreased and the aircraft will touch down again instead of being thrown up due to the increase in incidence, and therefore lift, experienced with the normal aircraft.

The author's own conclusion is that for land planes with the normal type of undercarriage and present flaps used over, say, half the span of the wing, it is difficult to foresee any considerable increase in wing loading at landing above about 30lbs. per sq. ft. if present restrictions on landing distance over a barrier are to be maintained. The front wheel undercarriage promises to give a marked improvement in allowing higher wing loadings to be used for land planes, but the actual loadings possible can at present only be roughly calculated as we have no experience in the special technique of landing with such an undercarriage. Tentatively, the author suggests that a loading of about 40lbs. per sq. ft. with the three-wheel undercarriage will give a landing distance over the barrier approximately equivalent to that of a normal aircraft loaded to 30lbs. per sq. ft.

Other developments for which we are waiting are a form of lateral control which will allow the use of full span flaps and, of course, the wing of variable area which if not prohibitive in weight would meet most of the present requirements. The practical difficulties in making such a wing for modern high speed aircraft are enormous, but no doubt will be solved in time. It is known that several countries are working on this subject, but details of the designs are not available. One step towards the ideal variable area wing is the development of flaps which when extended increase the wing area. Several of this type are now available and give a useful reduction in landing speed, but unfortunately most of them cause little increase in drag, and therefore do not give much reduction in distance when used for landing over a barrier as they have little effect on the gliding angle and floating distance. They are, however, of considerable value for use on flying boats where reduction of landing speed, and hence of impact loads at alighting, is generally more important than any steepening of the glide. The Gouge flaps used on the Empire and trans-Atlantic boats are of this type, and there is no doubt that the excellent performance that has been obtained is due in part to the higher wing loading that can be used because of these flaps. For flying boats of normal types the present upper limit of loading appears to the author to be rather higher than for land planes with the present types of undercarriage, say, about 35lbs. per sq. ft. at alighting. This higher loading can be used, as in general the only limitation is the loads that are imposed on the structure when alighting at high speed in rough water.

The tentative limits with existing types of flap set by the author of 30lb. per sq. ft. for normal land planes, 40lb. per sq. ft. for land planes with the front wheel undercarriage, and 35lb. per sq. ft. for flying boats only refer to the landing condition, and if the expendable load is appreciable higher initial wing loadings may be used. For short range commercial aircraft the wing loading at the end of the range will be much the same as at take-off, but for trans-Atlantic or other long range flights there will obviously be a considerable relief in wing loading as the fuel is consumed. It would be reasonable to allow for this reduction in wing loading if some means of jettisoning fuel is provided so that an emergency landing at the beginning of the flight may be made in safety. For a trans-Atlantic aeroplane the fuel weight may be expected to be from 0.3 to 0.4 of the

initial all-up weight of the aircraft. Taking the lower figure and assuming that two-thirds of the total fuel load could be jettisoned we have a reduction in weight at alighting of 0.2 of the initial all-up weight. Thus if for a flying boat we fixed the wing loading at alighting at 35lb. per sq. ft. the initial wing loading could be 44lb. per sq. ft., a figure which is probably approaching the optimum loading for this type of aircraft with modern cleanness and power loadings. For a land plane limited to 30lb. per sq. ft. at landing the initial wing loading would be approximately 37lb. per sq. ft., or if a three-wheel undercarriage is used allowing a wing loading at landing of 40lb. per sq. ft. the initial loading would be approximately 50lb. per sq. ft. It will therefore be seen that the landing condition is a serious one in restricting the wing loading unless the expendable load is high. We must hope that the devices promising an easing of this limitation—the three-wheel undercarriage, full span flaps and extensible area devices—will soon be developed to an extent where they may be generally used.

4. Initial Rate of Climb.

A reasonably high initial rate of climb is desirable so that the barrier condition may be met and obstructions in the vicinity of the aerodrome may be cleared at a safe height. In general the conditions governing the climb are similar to those controlling take-off, so that if a normal unassisted take-off is attained the climb may be expected to be reasonably good. Variable pitch airscrews with engines rated to climb at 10 per cent. above normal r.p.m. have added considerably to the climbing performance of modern aircraft.

The initial rate of climb may be approximately expressed as :—*

$$\text{Initial rate of climb, ft. per sec.} = 33{,}000 \left\{ \eta_c/\lambda_c - (25\sqrt{w})/(375\, L/D) \right\}$$

where η_c = airscrew efficiency on climb.
λ_c = power loading on climb.
w = wing loading.
L/D = lift to drag ratio climbing.

If η_c/λ_c is high, or in other words the power loading is low, as it will be if the take-off is good, the effect of wing loading is small and a considerable increase can be allowed without causing an appreciable decrease in the rate of climb. If, however, the two terms become nearly equal the rate of climb will be small and the effect of wing loading great. Thus if some form of assisted take-off is used the initial rate of climb needs special attention as the power loading will probably be high, due to the extra load that can be carried. In general, however, the initial rate of climb does not appear to impose any serious restriction on wing loading, even for assisted take-off. The use of constant speed or infinitely variable pitch airscrews in place of two-pitch is of considerable assistance, for with a two-pitch airscrew the second pitch must be set either for take-off or climb as it is impossible fully to meet design conditions in both cases. If the take-off is difficult it is necessary to set the airscrew to absorb the maximum allowable take-off r.p.m. at a speed only slightly in excess of take-off speed. When the aircraft accelerates to climbing speed the airscrew will speed up and exceed climbing r.p.m. so that it will be necessary to change into coarse pitch. With a constant speed airscrew this difficulty is avoided and it is possible to obtain maximum permissible r.p.m. from the start of the run to the finish of the climb.

5. Ceiling.

The ceiling obtained is governed by the same factors as initial rate of climb, but the supercharged height of the engine is a powerful additional factor. Equation 4 may be modified to give an approximate height for the ceiling :—

$$\text{Rate of climb at any altitude above rated altitude} = 33{,}000 \left\{ \eta_c f(h)/\lambda_R f(h)_R - [25\sqrt{(w/\sigma)}]/[375\, L/D] \right\} \text{ ft. per sec.}$$

* Handbook of Aeronautics, Part II, page 176.

where λ_R is the power loading at rated altitude and $f(h)_R$ is the height horsepower factor at the rated altitude appropriate to a normally aspirated engine. At ceiling the rate of climb will be zero so:—

$$\eta_c f(h)/\lambda_R f(h)_R = [25\sqrt{(w/\sigma)}]/[375\, L/D] \quad . \quad . \quad . \quad . \quad (4)$$

and

$$f(h)\sqrt{\sigma} = 0.066\, \lambda_R f(h)_R \sqrt{w}/(\eta_c L/D_{max}). \quad . \quad . \quad . \quad (5)$$

This defines the ceiling for $f(h)\sqrt{\sigma}$ can be read from a graph of the standard $f(h)$ and σ values. It will be seen that $f(h)\sqrt{\sigma}$ at the ceiling depends directly upon $\sqrt{w}$, but here again the ceiling condition is not a particularly stringent one in fixing an upper limit to w, for in most cases the use of constant speed airscrews and engines running at 10 per cent. above normal r.p.m. will be sufficient to ensure a reasonable ceiling even if assisted take-off is used. The ceiling condition also depends upon the term L/D_{max}, thus showing the desirability of high aspect ratio.

6. Flight with One Engine Out.

In multi-engined aircraft it is desirable that level flight should be possible with one or more engines not running. D. W. Douglas in the 23rd Wilbur Wright Lecture* gave a very full treatment of this subject. The determining factors are the climbing power of the remaining engines, the induced drag, the drag of the stopped airscrews and the drag caused by the yawed or sideslipping attitude of the aircraft required to maintain straight flight. Modern multi-engined aircraft appear to be very stable directionally and in many cases it has been stated by pilots that no rudder is required to maintain straight flight when one engine fails. This is a desirable feature as it indicates that the additional drag will be small. As in the ceiling condition a high aspect ratio is desirable. A rough semi-empirical rule which holds surprisingly well for multi-engined aircraft with fixed pitch or two-pitch airscrews is that the loss in ceiling is 17,000 feet with half engine power (one out of two or two out of four engines cut out) and 7,000 feet with quarter power. These figures can be appreciably improved by the use of variable pitch airscrews which allow the operating airscrews to absorb full engine power (instead of being held down in r.p.m. by the lower forward speed of the aircraft) and by the use of feathering airscrews to reduce the drag of those which are stopped.

Care is needed in considering aircraft with highly supercharged engines as it may be found that flight with one engine stopped is possible at heights in the region of rated altitude, but that the machine will lose height if flying below rated altitude. In some cases it has been found that designs can apparently meet specified conditions for flight at 10,000 feet with one engine cut out, but that level flight above 12,000 feet, and below 9,000 feet, is not possible. This, of course, means that the aircraft will be reasonably safe if engine failure occurs above 9,000 feet, but unsafe if below that altitude and is an undesirable condition.

As with the other climbing conditions it will generally be found that reasonably good performance is possible with one out of two or two out of four engines operating if the take-off is good. If assisted take-off is used there may be difficulty in meeting these requirements, but as due to the landing condition it is probable that assisted take-off will only be used with long range aircraft where fuel expenditure or jettisoning is counted on to obtain a reasonable wing loading at landing it is not unreasonable to assume that some relief in load will be allowed for flight with one or more engines cut out. In this case there should be no difficulty in obtaining level flight at, say, 5,000 to 10,000 feet with one out of two or two out of four engines cut out and half fuel. It should then be possible for the aircraft to turn back or continue the flight in reasonable safety.

* Journal of the Royal Aeronautical Society, November, 1935.

7. TAKE-OFF.

The case of normal take-off will first be treated and then the several methods of assisted take-off which may be used will be discussed.

The distance to take-off is approximately given by the equation (Appendix II)

$$\text{Run to take-off} = V^2 / \{ 2g (T_m/W - \mu) \} \quad . \quad . \quad . \quad (6)$$

where V is the take-off speed ft. per second; T_m is the mean take-off thrust corrected for slipstream drag and is approximately the corrected thrust at 0.7 take-off speed; W is the all-up weight at take-off; and μ is the effective coefficient of friction.

This equation is reasonably correct if T_m/W is appreciably larger than μ, but gives an optimistic answer when the two terms approach each other in value, or in other words, when the take-off run is long. To show the effect of wing loading we may rewrite the equation as

$$\text{Run to take-off} = (w/C_L) / \{ g\rho (T_m/W - \mu) \} \quad . \quad . \quad (7)$$

from which it will be seen that the run depends directly upon w, thus showing the difficulties we are faced with in increasing wing loading above present values.

If we attempt to maintain present take-off distances for any increase in wing loading there are three quantities which we may alter:—

(i) The take-off lift coefficient;

(ii) The ratio thrust over weight which may be modified by increasing the airscrew thrust; or

(iii) The coefficient of friction.

(i) TAKE-OFF LIFT COEFFICIENT.

The maximum lift coefficient can now be considerably increased by the use of flaps, and it has also been established that the take-off run can be reduced by their use if the thrust to weight ratio is high enough to mask the effect of the increase in drag that they cause. It has been recognised for some time that the slipstream from a wing or even nose engine increases the lift of a wing by virtue of the extra velocity, and this effect can be increased to an astonishing extent by the use of flaps. It is now possible to obtain a lift coefficient C_L at take-off of 2.4 for a twin-engined monoplane with low drag flaps, and by increasing the number of airscrews or their diameter or by decreasing the total wing area so that a larger proportion is covered by slipstream a considerable further increase should be possible. To obtain the maximum increase without inordinate drag it will be necessary to use flaps of low drag characteristics, although it has been found that quite a substantial decrease in take-off run can be obtained with the simple split flap if the thrust over weight ratio is high. Several of the low drag type of flap are now available, but most of them suffer from the disadvantage that they do not provide enough drag for the landing condition. What is needed is a low drag flap giving a substantial increase in lift coefficient at take-off, and which in addition can provide a high lift and high drag for landing. In the landing condition the amount of drag should preferably be under the control of the pilot, the lift being constant over a large range in drag so that the gliding path may be varied at will with but little change in speed. In several recent designs the take-off has had to be penalised by the fitting of high drag flaps required to meet the landing condition and there is real need of a dual purpose flap of the type described.

Messrs. Goodman-Crouch and Bolas have in America carried the idea of providing slipstream lift to the limit by using large airscrews and covering almost the whole of the wing with slipstream. In addition, the thrust axis is tilted downwards so that the effective angle of incidence of the wing is increased.

The use of slipstream on flaps considerably increases the effective lift coefficient at take-off and hence reduces the take-off distance, but unfortunately the distance from take-off to clearing a barrier is generally increased. Due to the lower take-off

speed the time taken to accelerate to climbing speed will be increased, and even if the pilot attempts to climb immediately after the take-off without accelerating the speed will be so far removed from best climbing speed that the rate of climb will be low. In spite of this increase, however, the distance from rest to clearing the barrier is in most cases considerably reduced by the use of slipstream on low drag flaps. One disadvantage of attempting to obtain as large a wing area as possible in the slipstream is that the drag at high speeds will be increased due to the extra velocity and turbulence of the slipstream.

(ii) Take-off Thrust.

The use of variable pitch airscrews in conjunction with engines allowing high power and r.p.m. at take-off gives a considerable increase in take-off thrust, particularly with fast aircraft fitted with highly supercharged engines where the coarse pitch airscrew is normally stalled at low speeds and therefore gives a low thrust. Two pitch airscrews show a considerable improvement over the fixed pitch airscrew, but are limited in their use as a single pitch cannot be used to give best take-off and best climb.

The use of an infinitely variable pitch or constant speed airscrew removes this difficulty, for the pitch may be reset to allow maximum permissible r.p.m. at any forward speed. The constant speed airscrew is desirable as the pilot need only set the control unit to the desired r.p.m. and the pitch change required will be obtained automatically. Thus best climb and best take-off may both be obtained.

An increase in take-off thrust may be obtained by designing the airscrew in its high pitch position for a speed lower than the normal cruising speed. This will be done by increasing the diameter or the blade width and decreasing the pitch for the cruising condition. A large increase in take-off thrust may then be obtained at the expense of a small decrease in airscrew efficiency at cruising speed. The engine designer can also be of assistance by allowing higher engine speeds, and possibly higher engine powers, at take-off. Of the two in general speed is the more important and in many cases a small increase in r.p.m. will give a large increase in take-off thrust, while a large increase in power has little effect. The engine r.p.m. can with advantage be increased until the tip speed of the airscrew approaches the speed of sound, at which speed there are serious tip losses which reduce the thrust. Thin bladed metal airscrews show less tip loss due to high speed than the thicker sections used for wooden airscrews, so that higher tip speeds may be allowed in the former case. There is also evidence showing that the Clark-Y section suffers less from very high tip speeds than does the R.A.F.-6 section, although the latter gives a better thrust when the blades are stalled. To show the effect of the main variables, Figs. 5 and 6 have been prepared from the best available data. The take-off thrust is given in terms of the thrust in the designed cruising condition and is the thrust at a speed of 0.7 take-off speed, which for a simple analysis may be considered as the mean take-off thrust. The difference between the various conditions would have been greater at lower air speeds, and particularly in the static condition, but these cases do not so well show the general effect on the take-off. The r.p.m. and b.h.p. are given in terms of the r.p.m. and b.h.p. in the cruising condition, which is assumed to be at the " normal " or " international " r.p.m. of the engine. The power in this cruising condition will be approximately two-thirds of the maximum power for level flight. Fig. 5 shows the effect of the design conditions for the airscrew and of the allowable r.p.m. for a representative take-off power curve. Curves 1-5 refer to different design condition of an airscrew suitable for flight at 250 m.p.h. at 5,000 feet, while curves 6 and 7 refer to airscrews designed for the same aircraft with a similar engine supercharged to 25,000 feet, which with the same power will give a speed of 300 m.p.h. The line A-A defines normal r.p.m., which before the general use of V.P. airscrews would be the maximum allowable r.p.m. at take-off, while B-B defines the r.p.m. at 10 per cent. above "normal," which is now the

most usual rating for take-off with variable pitch airscrews. Line C-C is at "maximum r.p.m. in level flight," and D-D at 10 per cent. above "maximum r.p.m. in level flight," these two conditions being concessions which may be granted by engine manufacturers in the future if the advantages to be gained are sufficient to warrant the allowance of the higher engine loads. Already some American engines are rated for take-off at r.p.m. closely approaching the 10 per cent. over "maximum r.p.m. in level flight."

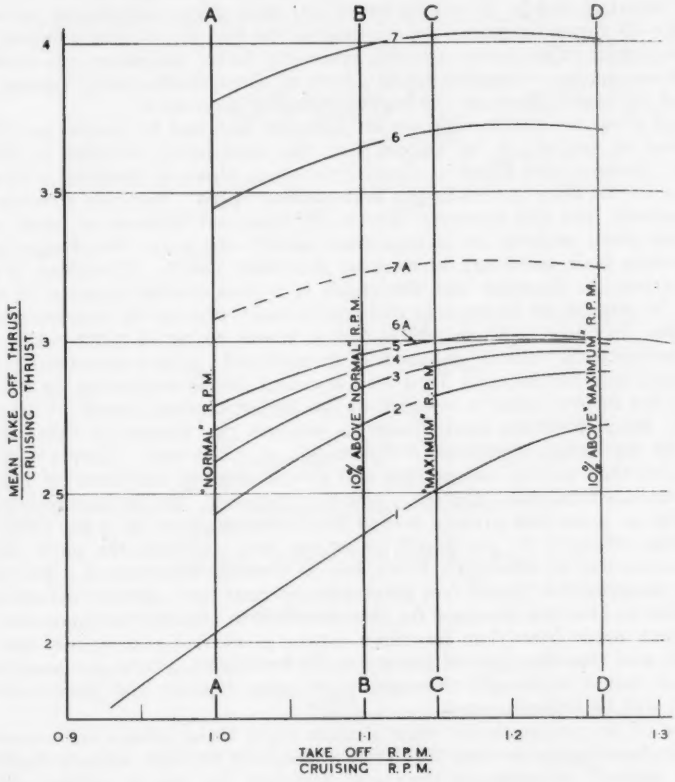


FIG. 5.

Mean take-off thrust.

Effect of airscrew-engine conditions for typical take-off power curve.

Curve 1 shows the thrust ratio for an airscrew designed to give optimum efficiency at the cruising condition. The thrust given by a fixed pitch airscrew is shown at the left-hand end of the curve, and it will be seen that a 32 per cent. increase in thrust may be obtained with a V.P. airscrew with the usual engine condition of 10 per cent. above normal r.p.m., while a 40 per cent. increase is given by allowing "maximum r.p.m. in level flight" and 52 per cent. increase by allowing 10 per cent. over "maximum r.p.m. in level flight." The airscrew of curve 1, as explained before, is designed for maximum efficiency at the cruising condition, and for a reasonable blade width the diameter is lower than could be allowed from the point of view of tip speed loss and airscrew noise when cruising. Curves 2, 3, 4 and 5 show the take-off thrust of similar airscrews of increasing

diameter but the same solidity, the last one of which gives a helical tip speed of 800ft. per second at cruising, which is arbitrarily assumed to be the upper limit.

Curve 2 is for an airscrew of slightly larger diameter than 1 which gives a loss of half per cent. in efficiency when cruising, and the increase in take-off thrust is astonishing, particularly when it is realised that the loss in cruising speed will be only about one half m.p.h. Curves 3, 4 and 5 are for similar airscrews of increasing diameter, giving losses in efficiency at cruising of 1, 2 and 3 per cent. respectively. The last of these airscrews will give a loss in cruising speed of about 2½ m.p.h. It will be noted that these curves are closing up and that little take-off thrust is gained by increasing the loss in cruising efficiency from 2 to 3 per cent. The curves are also becoming flatter and show less increase in thrust from increase in engine r.p.m., both of these results being caused by the increased tip speed effect on the higher diameter airscrews.

Curve 6 gives the thrust ratio for an airscrew designed for maximum efficiency at a speed of 300 m.p.h. at 25,000 feet, this case being included to show the effect of " stratosphere flight." Curve 7 is for an airscrew designed with a 2 per cent. loss in efficiency at this height and cruising speed. For this airscrew it has been assumed that the diameter cannot be increased because of noise and tip speed loss when cruising or at maximum speed. To lower the design speed it has therefore been necessary to increase the blade width. The effect is similar to an increase in diameter and the result is a considerable increase in take-off thrust. In general, an increase in diameter is more effective in increasing take-off thrust than increase in blade width, but it ceases to be of value when the tip speeds approach the velocity of sound. Curves 6 and 7 give a considerably greater thrust ratio than curves 1-5. To a certain extent this is misleading as the design thrust in the former cases is low due to the higher cruising speed. Curves 6(a) and 7(a) have therefore been drawn to indicate the thrusts in cases 6 and 7 relative to the design condition of 250 m.p.h. at 5,000 feet. Curves 6(a), 7(a) and 1-5 are then strictly comparable and give a relative indication of the actual take-off thrusts available. Curves 5 and 6(a) coincide, and an airscrew which at 250 m.p.h. at 5,000 feet gives a loss in maximum efficiency of 3 per cent. works at optimum efficiency at 300 m.p.h. at 25,000 feet, although the pitch angles in the two cases will be different. For a loss in cruising efficiency of 2 per cent. an airscrew designed for 25,000 feet gives about 10 per cent. greater actual take-off thrust than an airscrew designed for the same loss in efficiency at 5,000 feet. The assumptions made here that the same power is available at 25,000 feet as at 5,000 feet and that the take-off powers in the two cases will be the same may be questioned, but it is thought that with multi-stage blowers and inter-coolers this condition will be approximated.

In view of the proposals for high altitude flight these results are encouraging as the conclusion must be that an airscrew designed for high altitude flight gives a better take-off performance than one designed for use at normal altitudes, provided that the same allowable r.p.m. and b.h.p. at take-off are given by the two engines. The reason for this is that the higher speed and lower density at altitude necessitates a larger diameter or greater solidity, both of which tend to increase take-off thrust. In practice difficulty may arise due to the considerably larger pitch change required in the case of the airscrew for the high altitude aircraft, but with most types of variable pitch airscrew this greater pitch change could be provided, although in some cases a slight addition in weight would be caused.

Fig. 6 has been plotted to show the effect of horse-power and engine speed on the thrust ratio for the two airscrews 1 and 6, that is, the airscrews designed for maximum efficiency for the two cases of flight at 250 m.p.h. at 5,000 feet and 300 m.p.h. at 25,000 feet. While Fig. 5 indicates the thrust obtained with a normal take-off power curve, the engine operating at constant boost (Fig. 6 is more general as no fixed relation between b.h.p. and r.p.m. is assumed) so that the change in thrust for increase of b.h.p. at constant r.p.m., or for increase

in r.p.m. at constant power, may be obtained. An examination of these curves shows that at low r.p.m. an increase in power (given by increased boost) gives little or no increase in thrust. In fact, after a very slight initial rise there is actually a drop in thrust. As the r.p.m. is increased the effect of power becomes greater, but even at 10 per cent. above " maximum permissible r.p.m. in level flight " the effect is comparatively small. On the other hand, increase in r.p.m. at constant power is a very powerful factor in increasing thrust. The chain dotted

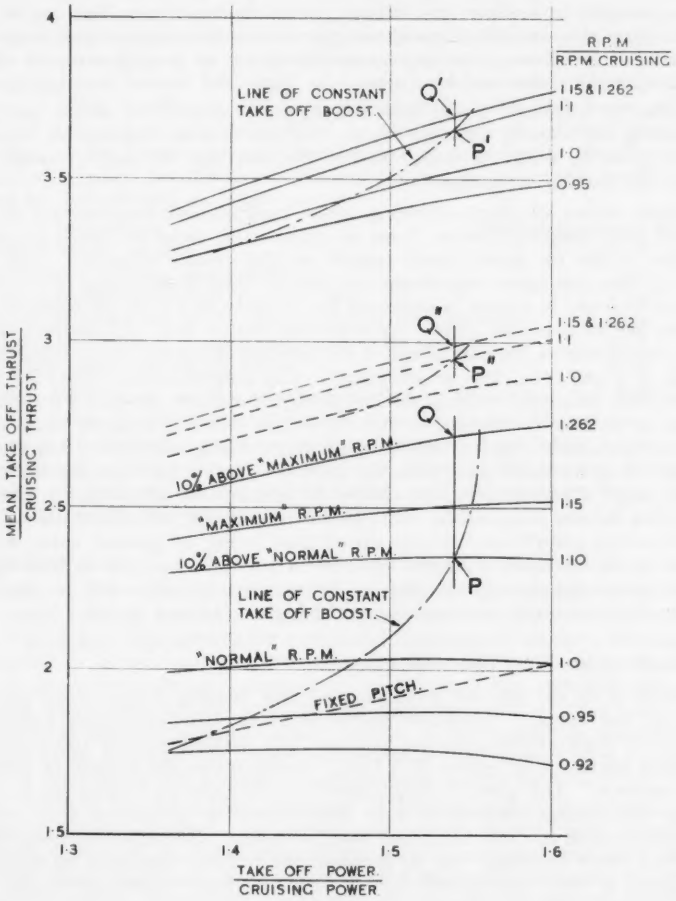


FIG. 6.

Mean take-off thrust.
Effect of power and r.p.m.

line drawn across the curves defines the conditions at which normal take-off boost is obtained, and the points on this curve therefore correspond with those in Fig. 5. Points to the left of this curve give engine conditions where the boost is lower than the maximum allowable and those to the right where it is higher. Thus there is the possibility of obtaining a considerable increase in thrust by allowing an increase in engine speed at constant power (or even reduced power)

by a reduction in take-off boost. This will, of course, mean that the airscrew pitch must be reduced so that its rate of rotation will increase, the pitch change being such that the same (or less) power is absorbed. For example, point P shows the usual limitation of 10 per cent. above normal r.p.m. at take-off boost. By allowing the r.p.m. to increase to 10 per cent. above "maximum r.p.m." at the same power but reduced boost the point Q is reached where the thrust is increased about 15 per cent., while even at a lower power but the same r.p.m. the increase in airscrew speed gives almost as great an increase in thrust. If it is not possible to increase the engine r.p.m. to this extent because of inertia loads the alternative is to fit a two-speed gear so that the engine r.p.m. may remain constant while airscrew r.p.m. is increased as much as is desirable. In this case the point Q will be obtained by a gear 1.17 times the normal cruising gear.

The effect of increased power with a fixed pitch airscrew is shown by a dotted line crossing the lines of constant r.p.m. In this case an appreciable increase in thrust is given by a rise in power due to the fact that the engine speed is also increased by the higher torque.

The upper series of curves referring to the high altitude airscrew are of similar form, but the change in thrust from an increase in airscrew speed is less, this being due to the tip speed losses caused by the greater diameter. The points P' and Q' have the same significance as before, and in this case it will be seen that little increase in thrust is obtained by increase of r.p.m. at constant power or by the use of a second gear. As explained before this high altitude airscrew may be considered as the equivalent of an airscrew designed for cruising at 5,000 feet with a 3 per cent. loss in efficiency. The dotted curves show the take-off thrust of this airscrew relative to the design condition at 5,000 feet, and the inference to be drawn therefore is that the device of using a larger diameter than that giving maximum cruising efficiency gives a thrust greater than that obtainable by the use of a two-speed gear with the normal airscrew and that the use of gears with the large diameter airscrew shows no appreciable advantage. The actual value of the thrusts obtained by these two methods will, of course, vary with the engine/airscrew conditions, the two-speed gear being of greater value when the tip speed of the increased diameter airscrew is low. An increase in cruising speed will also cause the two-speed gear to be of greater value due to the smaller diameter of the airscrew appropriate to the higher cruising speed.

(iii) Variation of Coefficient of Friction.

The term μ in the take-off equation includes bearing friction and the rolling friction of the tyres. There are therefore three main variables affecting the coefficient of friction—the bearing friction, tyre conditions and the condition of the ground surface. A recent N.A.C.A.* report gives the results of some tests on this subject. The general conclusions of the report are that on a concrete run way the rolling coefficients vary from 0.009 to 0.035, on firm turf from 0.023 to 0.054 and for soft turf from 0.064 to 0.077. The effect of plain bearings in place of roller bearings was to increase the rolling coefficient on concrete by about 0.007, a very considerable increase on the lower values obtained.

On concrete and firm turf the low and medium pressure tyres gave approximately the same value of rolling coefficient, while those for the extra low pressure tyres were considerably higher. On soft turf only the medium pressure tyres were tested. It is stated in the report that the tests were done at varying speeds, but unfortunately the effect of speed on the coefficients is not quoted. It is to be expected that on any but a smooth surface the effective rolling coefficient will increase appreciably with speed, due to the extra energy loss in the oleo leg and tyre caused by the unevenness of the surface. It is probable, however, that the

* N.A.C.A. Report No. 583. "The Rolling Friction of several Aeroplane Wheels and Tires," by J. W. Wetmore.

figures quoted above can be assumed to be the mean figures acting during a normal take-off run.

From other sources the rolling coefficient of a metal wheel on a rail is about 0.01, this being a comparatively high figure due to the friction of the flange, while the coefficient of friction of an aeroplane wheel on a smooth surface, such as the deck of a ship, is approximately 0.02.

Flying boats taking off from water present a problem in themselves and considerable work has been done in developing hull forms to give the lowest water and air drag, two conditions which in general are conflicting ones. As a very rough approximation used only to bring the flying boats into this general treatment the water drag may be considered to be given by an effective coefficient of friction (defined as water drag/load on water), a mean value for modern hulls being 0.22. This coefficient will vary considerably with hull form and all-up weight and will give an optimistic value for the take-off run if the thrust/weight ratio is low, as the hump drag will then become of considerable importance. The approximate value of the effective coefficient of friction for various conditions may therefore be summarised as below:—

Condition.	Effective Coefficient of Friction.
Metal wheel on rail	0.01
Aircraft wheel on ship's deck	0.02
Aircraft wheel on concrete run way	0.025
Aircraft wheel on grass aerodrome, normal surface ...	0.05
Aircraft wheel on grass aerodrome, poor surface ...	0.07
Flying boats taking off water	0.22

The very high value of the effective coefficient of friction for a flying boat (almost ten times greater than for a land plane on a concrete run way) explains the difficulty of obtaining good take-off for boats at high wing loading. To a certain extent this high value of effective μ is offset by the greater distance that is available for take-off, but in certain cases, such as operation from restricted harbours, this relief does not apply.

Take-off Distance.

The effect of the variables discussed above will now be considered with respect to the actual take-off distance. To show the effect of flaps and airscrew conditions, Fig. 7 has been plotted for a series of hypothetical designs for long range land planes. It is assumed that the all-up weight will be fixed by the take-off condition, the aircraft being increased in weight until the specified take-off run is reached, while the external geometry is kept the same so that wing loading will increase in proportion to the all-up weight. The increase in weight will not necessarily all be available for increased disposable load as part of it will probably be used to strengthen the structure and maintain design factors.

Curve 1 is for the fixed pitch airscrew of Fig. 5, curves 2, 3 and 4 for the airscrews 1, 2 and 5 of Fig. 5 at 10 per cent. above normal r.p.m. used without flaps, while curves 6, 7 and 8 are for the same airscrews used with low drag flaps. The effect of flaps on the take-off with a fixed pitch airscrew is not shown as the thrust/weight ratio is too low to give any appreciable advantage from their use. As explained before, the airscrews of curves 3 and 6 (Fig. 7) are appropriate to the two conditions of flight—300 m.p.h. at 25,000 feet at maximum efficiency or 250 m.p.h. at 5,000 feet with a 3 per cent. drop in efficiency. The difference between curves 2 and 3 and 5 and 6 represent the effect of stratosphere flight on the take-off, for the airscrews of these two conditions are designed for a maximum efficiency at 5,000 feet and 25,000 feet respectively. It will be seen that the high altitude airscrew gives an appreciable advantage in take-off run, or alternatively, in weight at take-off. A still further advantage can be obtained by designing the high altitude airscrew for a 2 per cent. drop in efficiency, giving the curves 4 and 7. In addition, it has already been shown that the wing loading for

optimum cruising at 25,000 feet is considerably lower than for normal altitudes. This will, therefore, lower the take-off speed and give a further advantage to the high altitude aircraft.

It will be seen that for a given take-off distance the difference between the weight at take-off of this series of aircraft, made possible by the use of variable pitch airscrews used with low drag flaps, represents the difference between a normal aeroplane and one which could undertake trans-Atlantic flight.

A similar series of curves could be drawn for an increase in wing loading at a constant all-up weight. In this case the increase in take-off distance with increase in wing loading would be slower as the thrust/weight ratio would not be decreased with increase in wing loading as it is in Fig. 7. The curves would, however, be of the same form.

The effect of the coefficient of friction μ on the take-off distance is shown in Figs. 8 and 9, in the former of which the third variable is take-off speed, the

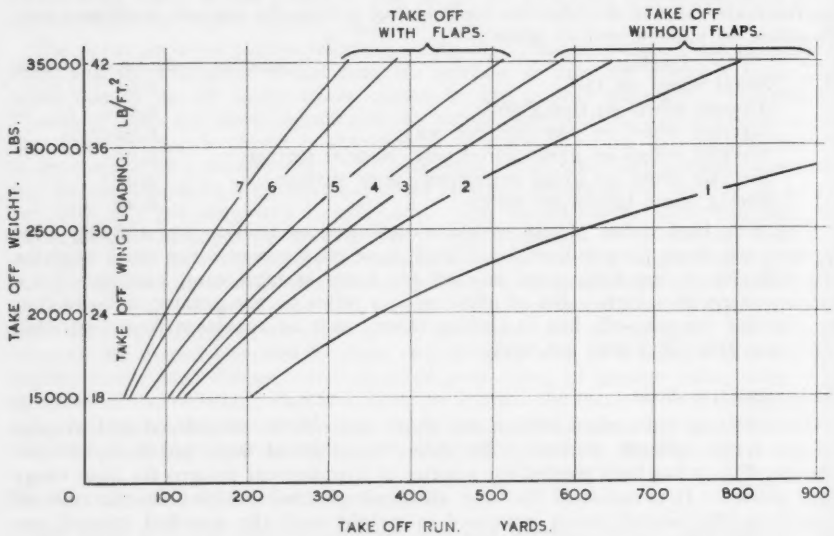


FIG. 7.

Influence of airscrew-engine conditions and of flaps on take-off mean.

thrust/weight ratio being constant, while in the latter thrust/weight is varied for a constant take-off speed. Both sets of curves are of similar shape, showing the increased effect of μ as the length of run is increased. The difference between the take-off distance for a flying boat at an effective μ of 0.22 and a land plane on a grass aerodrome is shown to be considerable, the former being about twice the latter for short runs, the proportion increasing very rapidly as the take-off speed is increased or the thrust/weight ratio decreased.

One method that has been suggested to overcome this disadvantage of the flying boat is to mount the boat on a trolley running on steel rails and allow it to accelerate under its own thrust up to take-off speed. The saving in distance may then be very considerable as the difference in effective μ will be approximately from 0.22 to 0.01, and as will be seen from Figs. 8 and 9 it should be possible to launch a boat in, say, 300 yards, which is not able to take off under its own power from water. It is believed that some American experiments are being made on these lines, but no details are available. The disadvantages are that

the ground space covered would be considerable, as at least two intersecting tracks would be required to avoid the danger of a side wind take-off.

The effect of concrete runways may also be seen from Figs. 8 and 9, and it will be noted that the advantage in take-off distance is small until the ground

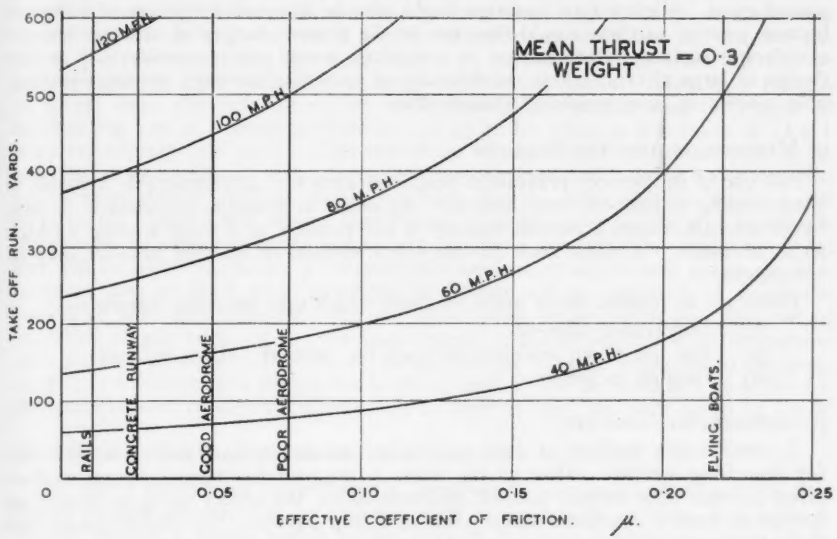


FIG. 8.

Effect of coefficient of friction and take-off speed on ground run.

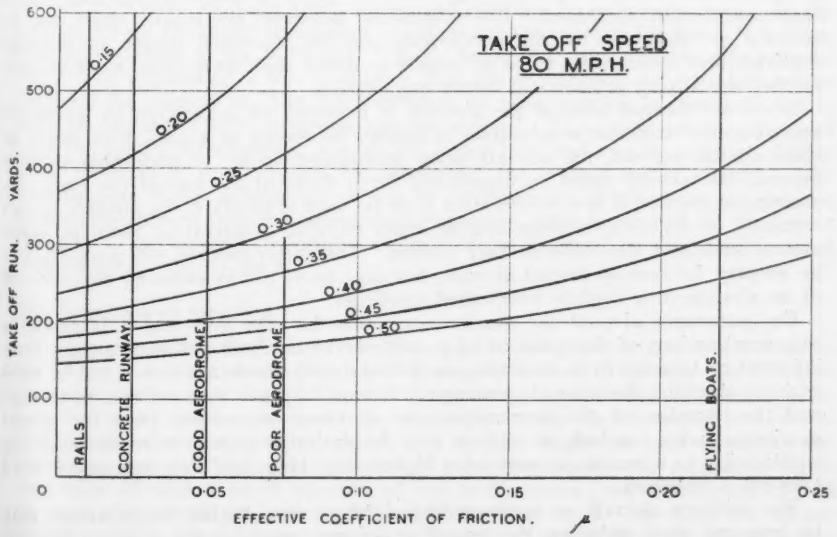


FIG. 9.

Effect of take-off speed and T/W on ground run.

run becomes considerable. Thus from the point of view of take-off run it appears to be uneconomical to put down runways unless the size of present aerodromes can be considerably increased. This is not to say that the use of concrete runways on normal sized aerodromes is condemned, for they can show several practical advantages, particularly in wet climates where grass aerodromes soon become waterlogged. Higher tyre loadings might also be adopted if the use of runways became general as there would then not be the present danger of sinking into the aerodrome surface. A reduction in tyre sizes would assist considerably in the design of large aircraft where the difficulty of providing stowage for large retractable wheels is now becoming considerable.

9. Methods of Assisted Take-off.

Full use of the devices previously described allows of a considerable increase in wing loading at take-off, but cases will still occur in practice, particularly in long range aircraft, where a normal take-off is not possible at a wing loading as high as is desirable. In cases such as this some method of assisted take-off may be considered.

There are at present three main methods which may be used, namely:—

(i) Accelerated take-off.
(ii) The use of an auxiliary aircraft for take-off (Mayo Scheme).
(iii) Fuelling in the air.

(i) Accelerated Take-off.

A considerable amount of data now exists on accelerators and catapults used for launching aircraft. Most of the work in the past has been done on medium sized aircraft with normal take-off characteristics, the object being to launch an aeroplane from a restricted space such as a ship's deck. The accelerations used have been comparatively high and the take-off speeds of the aircraft used have been low, both of which factors tend to shorten the length of runway required. Accelerators for use with modern, long range aircraft must deal with aeroplanes of considerable all-up weight and high take-off speeds so that the difficulties have been considerably increased. The difficulties, however, are mainly those due to increase in the power of the accelerator and the increased length of runway required, and there seems to be no reason to doubt that these could be overcome as they are simply problems of heavy engineering.

In an accelerated take-off the aircraft is mounted on a carriage to which an approximately constant acceleration is applied by means of a ram, wire ropes or some similar method, the aircraft being accelerated up to, or preferably slightly beyond, its take-off speed so that it will be in flight at the end of the run. An alternative method if low acceleration is to be used is to allow the aircraft to run normally on its undercarriage and to apply to it an accelerating force by some means, such as a wire rope haulage system. This latter method will probably not be adopted for heavily loaded aircraft, but may be of use in assisting the take-off of an aircraft in a slightly overloaded condition.

For passenger aircraft the accelerations must be kept low, and it is probable that accelerations of the order of $1\frac{1}{2}$ g. will not be much exceeded, although little information appears to be available on the maximum acceleration that can be used without alarming the normal passenger. It would appear that the rate of change and the duration of the acceleration are of more importance than the actual maximum value reached, so that it may be desirable gradually to increase the acceleration to a maximum somewhat higher than $1\frac{1}{2}$ g. and then decrease it until take-off is obtained.

For military aircraft or commercial freight carriers higher accelerations may be imposed, thus reducing the length of runway required for a given take-off speed. High accelerations, however, will impose large loads on the structure and will therefore necessitate an increase in structure weight, and it is therefore

probably more economical to increase the cost of the catapult by using a longer run with a lower acceleration rather than reduce the disposable load of the aircraft. Variable pitch airscrews will be necessary to ensure a safe rate of climb after launching, and if used in conjunction with low drag flaps will materially assist in reducing take-off speed, and hence the length of run. To obtain an idea of the length of run required we will assume that the wing loading of the most heavily loaded aircraft to be launched at low accelerations is 60lb. per sq. ft. By the use of V.P. airscrews and low drag flaps a C_L at take-off of at least 2.4 may be expected, giving a take-off speed of approximately 100 m.p.h. Allowing a margin of 10 per cent. the catapult design speed will be 110 m.p.h. and the length of accelerating run at a mean acceleration of $1\frac{1}{4}$ g. (to allow a maximum of $1\frac{1}{2}$ g.) is approximately 100 yards. The maximum all-up weight of the aircraft to be launched is more difficult to predict, but it may be expected to be at least 60,000lb. for economical trans-Atlantic flight, in which case the mean accelerating load will be 75,000lb. Thus it will be seen that the use of accelerators for the type of aircraft which may be expected in the future will involve a considerable outlay in capital and will in addition require a considerable amount of aerodrome space, as it is probable that at least four directions of launch will be required to avoid the danger of side wind take-off. On the other hand, depreciation and the cost of operation should be small and the maintenance required negligible in comparison with aircraft practice. The life of an accelerator may be expected to be long, so that in considering a design for large aircraft it will be necessary to allow for the requirements of aircraft which may be built in, say, the next 10 to 15 years.

(ii) Use of an Auxiliary Aircraft for Take-off.

The Mayo scheme for trans-Atlantic operation is now well known and the first flights of this aircraft will be watched with interest both at home and abroad. In this method a small, highly loaded aircraft for mail carrying is taken off by means of a larger, lightly loaded machine. The trans-Atlantic mail carrier is mounted on top of the parent machine and the two take-off and climb together. When sufficient altitude has been reached the two are separated and the smaller aircraft continues its flight while the parent machine returns to its base. In the present design the upper component is a float seaplane, while the lower is a flying boat very similar to the " Empire " flying boats, but with considerably reduced load. The advantage of this method is that the operational aircraft need not be designed for take-off so that this limitation on wing loading is removed, and in addition the use of V.P. airscrews may be avoided. The lower component, apart from the special attachments, is a normal flying boat and may be used for charter work when it is not required for launching the trans-Atlantic aircraft. The disadvantage of this scheme appears to be the limitation in all-up weight imposed by the requirement that the operational component must be carried by the parent aircraft. This method, therefore, appears to be confined to the medium sized mail carrying type of aircraft.

(iii) Fuelling in the Air.

A very convincing display of fuelling in the air was given at this year's Hendon Air Display, and the method by which a drogue is used to draw in the fuel pipe to the aircraft to be fuelled appears to remove many of the difficulties to be expected when fuelling is attempted at comparatively high speeds. For trans-Atlantic or other long range aircraft this method might be used to reduce the limitation in weight imposed by take-off requirements, for the aeroplane would then take off with a small quantity of fuel in the tanks (say a minimum of half an hour allowance) and the tanks would be filled in the air from the tanker aircraft. With trans-Atlantic aircraft, where about one-third of the all-up weight of the aircraft is made up of fuel, this method would obviously show a considerable advantage and would allow a large increase in wing loading to be made while still

maintaining a normal run at take-off. The disadvantages are that the amount of fuel that has to be transferred will be so large (a normal trans-Atlantic machine may require from 2,000 to 3,000 gallons of fuel) that a considerable time will be required to complete the fuelling and the size of the tanker will be comparable to that of the trans-Atlantic aircraft itself.

10. Summary.

The main points of the paper may be summarised as follows. A consideration of the optimum wing loading for cruising leads us to the conclusion that for modern, clean, high performance aircraft the wing loading could with advantage be considerably increased to loadings of the order of 60lb. per sq. ft., or even higher, if the two main restrictions of landing and take-off could be eased. For normal, medium range aircraft of fairly low power loading the most serious restriction limiting the loading to a lower value than is desirable is the landing run. With the present type of flaps this appears to impose an upper limit of wing loading of about 30lb. per sq. ft. for land planes, 35lb. per sq. ft. for flying boats and 40lb. per sq. ft. for land planes with a front wheel undercarriage.

With long range aircraft the landing condition is eased due to the consumption of fuel, and the take-off limitation then becomes severe. The effect of this limitation may be reduced by the use of high thrust airscrews working in front of low drag flaps or by one of the methods of assisted take-off.

The device of designing an airscrew for a lower speed than normal and allowing a small drop in efficiency when cruising gives a considerable increase in take-off thrust and reduces the value of two-speed gears.

With flight at heights of the order of 30,000ft. there appears to be no difficulty in obtaining a reasonable take-off distance as the take-off thrust may be expected to be higher and the wing loading lower than for an aircraft designed for flight at normal altitudes.

An examination of the generalised take-off equation shows that little advantage in take-off run is to be gained by the use of concrete runways until runs on the ground of the order of 600 yards can be allowed.

Appendix I.

The Optimum Wing Loading for Speed.

This method was first brought to our notice by Mr. J. M. Gray.

The simple speed equation is

$$\eta \text{ b.h.p.} = DV/550$$

where D is the total drag at a speed V ft. per sec. and η is the airscrew efficiency.

Now

$$D = \sigma P\,(V/100)^2 + (a + bC_L^2)\,(\rho_0 \sigma S V^2/2)$$

where P is the " extra to wing " parasite drag at 100ft. per sec. and a and b the wing profile and wing induced drag coefficients.

Thus

$$D = \{\,(2P/\rho_0 \sigma S V^2) \times (V^2\sigma/100^2) + a + bC_L^2\,\}\,(\rho_0 \sigma S V^2/2)$$
$$= \{\,2Pw/(\rho_0 W\, 100^2) + a + 4\,w^2 b/(\rho_0^2 \sigma^2 V^4)\,\}\,(\rho_0 \sigma W V^2/2\,w)$$

and

$$\eta \text{ b.h.p.} = \{\,(2/100^2)\,(P/W)\,(w/\rho_0)$$
$$+ a + 4\,w^2 b/(\rho_0^2 \sigma^2 V^4)\,\}\,(\rho_0 \sigma W V^2/2\,w)\; V/550$$
$$(550\,\eta \text{ b.h.p.})/\rho_0 W = (P\sigma V^3)/(W\, 100^2\, \rho_0) + a\,(\sigma V^3/2\,w) + b\,(2\,w/\rho^2 \sigma V).$$

Multiply throughout by $w\rho$ and arrange as a quadratic in w.

$$(2\,b/\rho_0 \sigma V)\,w^2 + \{\,(P\sigma V^3)/(100^2\,W) - (550\,\eta \text{ b.h.p.})/W\,\}\,w + a\rho_0 \sigma V^3/2 = 0.$$

This is of the form $Aw^2 + Bw + C = 0$; w and therefore V will be a maximum when $B^2 = 4\,AC$ and then $w = -B/2\,A$.

Thus for optimum loading

$$\{ (P\sigma V^3)/(100^2\ W) - (550\ \eta\ \text{b.h.p.})/W \}^2 = 4\ ab\ V^2$$

$$(P\sigma V^3)/(100^2\ W) - (550\ \eta\ \text{b.h.p.})/W = \pm 2\ V\sqrt{(ab)}.$$

The negative root is the real one so we have

$$550\ \eta/\lambda = (P\sigma V^3)/(100^2\ W) + 2\ V\sqrt{(ab)} \quad . \quad . \quad . \quad (1)$$

where λ is the power loading W/b.h.p. This equation defines V the optimum speed.

Now

$$w = -B/2\ A = 2\ V\sqrt{(ab)}/2\ .\ \rho_o \sigma V/2\ b.$$

Thus w the optimum loading is given by

$$w = \tfrac{1}{2}\ \rho_o \sigma V^2 \sqrt{(a/b)} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This is defined when V is known and is the wing loading at which the wing develops its maximum L/D in the cruising condition.

Discussion.—It is assumed in this method that the wing drag coefficient can be expressed in the form

$$C_D = (a + bC_L^2)$$

where a is the minimum wing profile drag coefficient and bC_L^2 the induced drag coefficient.

This is not precisely true, but in modern aerofoil tests at high Reynolds numbers it will be found that the approximation is good over the range covered by top speed, cruising flight and climb, except near the ceiling.

Another assumption is that the " extra to wing " parasite drag is independent of wing area. This assumption cannot be so well justified as the drag may be decreased as wing area is reduced by the use of a smaller tailplane and a shortening of the fuselage, but on the other hand it may lead to an increase in drag due to the larger proportion of the wing area affected by body-wing, nacelle-wing and nacelle-body interference. In addition the stowage space in the wings will be reduced by the smaller wing area and in some cases this will necessitate an increase in body size.

Thus it may be necessary to make a re-estimate of the drag after the first approximation to V and w. The effect will not be great, however, and may be neglected for preliminary work.

Appendix II.

Take-off Run.

At any instant during the take-off run the accelerating force is:—

$$T - \mu W - (D - \mu L)$$

where T is the airscrew thrust corrected for slipstream drag and body interference, μ is the effective coefficient of rolling friction, and D and L are the drag and lift respectively.

Expressing the drag and lift in terms of the usual coefficients we have:—

$$\text{Accelerating force} = T - \mu W - \{ (C_D - \mu C_L)/2 \}\ \rho S V^2.$$

Now for modern aircraft the term $(C_D - \mu C_L)$ during the take-off run is very small and little error is introduced in assuming it to be zero. Also it can be shown that an extremely good approximation is given by assuming the mean thrust during the run to be the net thrust of 0.7 take-off speed.*

Thus the accelerating force simplifies to:—

$$T_M - \mu W$$

* N.A.C.A. Technical Note No. 557.

where T_M is the net thrust at 0.7 take-off speed. The distance to take-off at a speed V will then be:—

$$V^2W/\{2g(T_M-\mu W)\} = V^2/\{2g(T_M/W-\mu)\}$$

This expression can only be an approximate one, but is not seriously in error if the slipstream drag is included in estimating T_M and T_M/W is appreciably greater than μ. It will tend to become more optimistic as the two terms approach, or in other words, as the run becomes long.

Discussion.

The Chairman: He congratulated the author on his comprehensive review of present-day knowledge of wing loading and take-off problems. With regard to the stress laid upon the desirability of providing high wing loadings and low power loadings, he said that, assuming devices were introduced to overcome the difficulties arising from the high wing loadings at take-off and landing, the location of the airscrews and engines might become the important question. The low power loadings would necessitate large airscrews and engines, and the high wing loadings would reduce the wing span and depth, and he asked if the author had considered which was the best arrangement of airscrews for use with the suggested very high wing loadings.

The Chairman reminded the meeting that the author had asked that discussion of the three-wheel undercarriage should be deferred until December 2nd, when Squadron Leader Fraser would lecture to the Society.

Major R. E. Penny (*Associate Fellow*): As a protagonist of the flying boat, he felt it had come off rather badly in the paper. In order to secure the benefit of very large surface loadings, such as the author had mentioned, machines must be very large. In a trans-Atlantic aircraft working at a surface loading of 60lbs. per sq. ft. there would not be space for either the pay load or the fuel if the all-up weight of the machine were less than 100,000lbs. He asked how a flying boat and an aeroplane of trans-Atlantic range and of the all-up weight of 100,000lbs. would compare in efficiency, even assuming that the aeroplane were fitted with the three-wheel undercarriage. In the case of the flying boat having assisted take-off, one had to arrange for the landing condition only, *i.e.*, the water clearance of the airscrew could be reduced to the absolute minimum; further, the depth of the hull would only need to be just sufficient for the passengers and fuel. Therefore, a very efficient hull form could be designed, having practically a positive metacentric height. That meant that the wing tip floats could be very small and could be folded nicely into the engine mountings, so that the machine became very nearly a flying wing. He asked how the tricycle undercarriage could be folded away effectively on the aeroplane and what would be the effect of the weight of the undercarriage in a machine of such large all-up weight. If the thrust were unimportant in a machine having assisted take-off, was there any advantage in using the high pitch/diameter ratio airscrew? The airscrew problem would become exceedingly important with high-powered engines. Engines approaching 2,500 h.p. were in sight, so that we should have 3,000 and 4,000 h.p. engines before very long, and great difficulties would confront the airscrew constructor. He believed the problems would be solved by the assisted take-off and the use of airscrews of high pitch/diameter ratio, and that we should gain advantages in other directions by pursuing that line of attack. In flying boats, he added, which operated over the sea, the climb was unimportant.

Dr. G. V. Lachmann (F.R.Ae.S.): With reference to equation (1), giving the optimum wing loading, and the expression for the optimum speed, he said it was well-known that minimum fuel for a specified range was obtained when flying at best L/D, and the condition for (L/D) max. was that the total parasitic drag (body + profile drag) equalled the induced drag. As far as he knew this law had

been predicted long before any aeroplane had flown by Penaud, 1870, and it had been clearly established later by Lanchester (" Aerodynamics " Prop. I, §164).

If

$$C_{Di} = k\,(C_L^2/\pi A) = C_p$$

the optimum C_L becomes

$$C_L = (\pi A C_{dp}/k)^{\frac{1}{2}}.$$

Therefore the optimum wing loading was

$$W/S = \tfrac{1}{2}\,\sigma\rho v^2\,(\pi A C_{Dp}/k)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (I)$$

and the connection between speed and horsepower was

$$550 \text{ h.p. } \eta = 2\,Wv\,\{\,(C_{Dp})/(\pi A/k)\,\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (II)$$

These formulæ were considered a little more transparent than those of the lecturer, for he thought they brought out the physical facts a little clearer.

(*Communicated.*)

1. The formulæ above refer to an aeroplane of *given size*. The expression for the optimum value of C_L corresponding to best L/D is obtained by partial differentiation of the equation for C_L/C_D with respect to C_L.

$$C_L/C_D = C_L/\{\,k\,(C_L^2/\pi A) + C_{dp}\,\}$$
$$\partial\,(C_L/C_d)/\partial C_L = -1/(kC_L^2/\pi A) + 1/C_{dp}$$

hence

$$k\,(C_L^2/\pi A) = C_{dp}.$$

On this assumption the lift coefficient corresponding to max. L/D is determined and, neglecting the influence of speed on propeller efficiency and of throttling on specific petrol consumption, the pilot would have to vary *ASI* by throttling as the total weight is diminished during a long distance flight in order to obtain minimum petrol consumption or maximum range.

As the term " optimum speed " is usually applied to this condition and misinterpreting an introductory remark by Mr. Vessey in regard to minimum fuel for a specified range, he was under the erroneous impression that the author was out to establish this case.

After having read the paper, and thanks to Mr. Belart's remarks, he appreciated that the problem in question is in fact to determine the minimum wing surface or the maximum speed with the following quantities assumed to be given :—

All-up weight, relative density, horse-power, area of parasitic drag and effective aspect ratio.

The wing area being variable the condition of least drag is then established by partial differentiation of the equation for total drag with respect to S.

$$D_{tot} = C_o S q + a_p q + kW^2/(\pi q A S)$$

where

C_o = coefficient of profile drag (assumed to be constant).
a_p = area of parasitic drag.
k = factor indicating the ratio of actual induced drag to that of elliptical lift distribution.
A = aspect ratio $= 4\,s^2/S$.
$q = \tfrac{1}{2}\,\sigma\rho v^2$.

$$(\partial/\partial S)\,D_{tot} = C_o q - kW^2/(\pi q A S^2)$$

or

$$C_o q S = kW^2/(\pi q A S);\quad C_o = C_{di},$$

i.e., Profile Drag = Induced Drag.

This is a corollary to the principle referred to before (established by Lanchester (" Aerodynamics," Prop. IV, 165)) which defines the condition of least drag with variable wing surface.

In view of this law the following expressions can be written down immediately:

$$(D_{tot})_{min} = 2\,C_o qS + a_p q \quad \text{(least drag)} \quad . \quad . \quad . \quad (1)$$

$$S_{min} = W/q\ \{\ (\pi AC_o/k)\ \}^{\frac{1}{2}} \quad \text{(min. wing surface)} \quad . \quad . \quad (2)$$

$$(W/S)\ \text{opt.} = q\ \{\ (\pi AC_o/k)\ \}^{\frac{1}{2}} \quad \text{(opt. wing loading)} \quad . \quad . \quad (3)$$

$$550\,\eta\ \text{h.p.} = 2\,vW\ \{\ C_o/(\pi A/k)\ \}^{\frac{1}{2}} + \tfrac{1}{2}\,\sigma\rho a_p v^3$$

$$\text{(connection between speed and h.p.)} \quad . \quad . \quad . \quad (4)$$

It is obvious that equations (3) and (4) are transformed into (I) and (II) given in the original discussion remarks as a_p becomes zero, and $C_{dp} = C_o$, *i.e.*, in the case of the ideal all-wing aeroplane.

One can easily verify that equations (3) and (4) are equivalent to the corresponding expressions given by Mr. Vessey; however, little purpose is served in the writer's opinion from the point of view of physical clarity and easy practical application in replacing the first hand design terms of horse-power and weight by the derived term "power loading" or by introducing the rather worn out conception of "parasitic drag at 100 ft./sec." which only helps to camouflage a very old and fundamental principle of aeromechanics.

2. The Case of All-Wing Aircraft.

One cannot quite accept Mr. Vessey's arguments in regard to the flying wing or allowing aircraft flying at high altitudes at optimum speed. According to Mr. Vessey "the wing loadings involved would be enormous and the speeds fictitious." Surely, the result depends on whether the basic assumptions are reasonable.

Assume, for example, the following data as given:—

$$W = 30{,}000\text{lbs.}$$
$$v_{cruis} = 400\ \text{m.p.h.}$$
$$\eta = 0.85$$
$$C_o = 0.006$$
$$A = 10$$
$$k = 1$$

The horse-power required becomes

$$\text{h.p.} = 2\,Wv\,(C_o/\pi A)^{\frac{1}{2}}/550\,\eta = 1{,}070.$$

The wing loading follows from

$$W/S = \tfrac{1}{2}\,\sigma\rho v^2\,(\pi AC_o)^{\frac{1}{2}}.$$

For sea level $W/S = 180$ lbs./sq. ft.

At 30,000ft.

$$\sigma = 0.374,\quad W/S = 67.5\ \text{lbs./sq. ft.}$$

It is obvious that with a wing loading of 180 lbs./sq. ft. a safe landing and an ordinary take-off are out of question, and an assisted take-off would require excessive accelerations.

With the lower wing loading, corresponding to optimum cruising speed at 30,000ft., and assuming the use of slotted flaps (take-off $C_L = 2$), constant speed airscrews and a take-off horse-power twice the cruising h.p. the unstick run would be about 790 yards and the total take-off run to clear a 50ft. obstacle 1,037 yards, *i.e.*, about twice the maximum permitted length. Using the prepared runway of a large aerodrome there should be no objection to a total take-off length of 1,000 yards in the case of long distance aircraft. Alternatively, with assisted take-off and applying an acceleration of $\frac{1}{2}g$. the unstick run would be about 300 yards and the total distance to clear the obstacle 547 yards. As probably about half of the total weight would be carried in the form of petrol, the wing loading on landing would be reduced to a little over 30 lbs./sq. ft. By the use of suitable high lift and high drag devices and employing powerful brakes and a tricycle undercarriage landing at about 100 m.p.h. should not offer great difficulties on a reasonably large aerodrome. Cruising at high altitude under optimum conditions is therefore an essential condition for all-wing aircraft.

Mr. Vessey suggests that the wing area of an all-wing aircraft should be increased for the sake of gaining stowage space, and also in order to satisfy the formulated conditions of optimum speed. There is no point in satisfying the aerodynamic ideal of the all-wing aircraft " à tout prix " if the stowage space provided inside the wing of minimum dimensions is insufficient, as it would also be a wrong policy to increase the wing size for the purpose of increasing stowage space in order to get a fuselage of minimum dimensions on conventional designs.

The purpose of any load-carrying aeroplane is to carry a load of passengers or military equipment at a high speed with the least expenditure of horse-power. As the ideal of the perfectly streamlined aeroplane is nearly accomplished and since practically all drag is due to skin friction, the decisive problem for the designer is to create a shell around the required space which offers the minimum wetted surface. From this point of view a relatively short airship shaped body is superior to an aerofoil.

It can be shown* that the connection between total wetted surface and the volume of the wing is

$$S_t = CV^{\frac{2}{3}}$$

where S_t = total wetted surface.

V = volume.

C = constant dependent on aerofoil used and aspect ratio.

The value of C for an aspect ratio of 7 and a typical wing section is about 13, while the equivalent constant for a streamlined fuselage ($l = 5$ diameter) is about 6.8. Therefore, with the same stowage space, the wetted surface of a streamlined body is about one half that of a portion of the wings having the same stowage capacity. If the volume inside the wings of minimum dimensions is insufficient to stow the required load, crew and passengers, it is much more economical to add a streamlined body having the required capacity than to strive for accomplishing the ideal of the flying wing having a larger area.

Dr. H. Roxbee Cox (*Fellow*): On broad principles he was in agreement with the author. When discussing the effects of aspect ratio on performance it was usual to consider the problem purely as one of aerodynamics; and Mr. Vessey was a pioneer, for he had introduced structure weight as a consideration in the problem of the effects of aspect ratio. But one wished that he had been able to discuss that problem in a quantitative way. Admittedly that would be difficult, but it would be helpful if Mr. Vessey could show why, in a written reply, he thought that the interference effect outweighed the structure weight effect. With a decrease in aspect ratio the thicker wings could carry more load within them and so there should be a smaller fuselage; this gave one source of decrease in structure weight; the wing structure weight would also be reduced, so one should have a smaller aeroplane. Would not its speed show an increase? If Mr. Vessey could consider the matter from that point of view and give some figures they would be of interest.

Great interest attached to Mr. Vessey's curve showing where the optimum wing loading was likely to come. Dr. Roxbee Cox said he believed that high wing loadings would be upon them very soon; and there were many reasons for that. One was that the tendency must be for the " density " of an aeroplane to be constant. A passenger would expect to occupy the same amount of space, whether he was using a large or small aeroplane; and in aircraft for the same sort of duty presumably the volume of the fuel carried would bear a roughly constant relation to the volume of the aeroplane, and so on. If the " density " of an aeroplane tended to remain constant, the wing loading would increase proportionately with the linear dimensions. So that if they were to have big aeroplanes the tendency would be towards high wing loadings.

The paper had indicated that so long as the present general shape of aeroplanes was retained they would very soon reach a position in regard to wing loading

* Lachmann. " Skin friction from the point of view of the Aeronautical Engineer." Cambridge University Engineering and Aeronautical Society's Journal, 1937.

beyond which it was not worth going. In the case of the flying wing, however, there was, practically, no such limit. It seemed that they would have to compromise between the flying wing and their present lay-out, producing a machine with less fuselage and more wings for which the optimum wing loading was much higher. In that connection, low aspect ratio would be helpful. He would not carry that argument too far and suggest an aspect ratio of 2 or 3; but there being apparently two schools of thought among designers, some favouring an aspect ratio in the region of 6 and others favouring round about 10, he ranged himself definitely with the " sixers."

He was not quite clear why, except in the case of assisted take-off machines of the composite aeroplane variety, the take-off loading of a flying boat could be so much bigger than the alighting value.

A flying boat taking off frequently fell back on to the water before making its final get away; in other words, something like the landing condition could occur during take-off.

Finally, he asked if it were really obvious that the nett result of tilting the airscrew axis downwards in the Booth-Bolas design would be a gain. It was not obvious to him and he would like to know if he had overlooked some elementary reason.

Mr. Hollis Williams (*Fellow*): He regretted that Mr. Vessey had asked speakers to hold over any remarks concerning the tricycle chassis until Squadron Leader Fraser's lecture at a later date, as he was anxious to make some contributions on this subject. All he would say, however, on this occasion was that the tricycle type of undercarriage would be found to have an important influence on take-off distance.

As to the effect of ground conditions upon take-off, he disagreed emphatically with the view that concrete runways were not of great benefit. Although the author's curve seemed to indicate that there was only a small difference in ease of take-off as between a concrete runway and the ground of a very good aerodrome, it should be borne in mind that a very good aerodrome became a very bad aerodrome as the result of a little rain. Wheel sizes and diameters had to be selected to give a reasonable bearing on wet aerodromes. If it were a general practice to use concrete runways it would be possible to reduce the size of wheels, and much of the trouble experienced nowadays in regard to retracting the undercarriage would be eliminated.

Dr. H. C. H. Townend (*Fellow*): He would like to repeat Dr. Roxbee Cox's question about the gain resulting from inclining the airscrews downwards. At first sight it appeared that what was gained by the favourable change in incidence might be lost by the unfavourable downward component of the thrust. It looked to him, in fact, like the old fallacy of lifting oneself up by the boot straps. No doubt the effect was genuine, but he could not quite see the mechanism by which it came about.

Mr. H. Belart (*Associate Fellow*): He would like to comment on the first part of the paper dealing with optimum wing loading which he thought gave a most remarkable outlook for further aerodynamic development.

Regarding the conditions for optimum speed and efficiency, he pointed out that the expression for this condition developed by Dr. Lachmann in the discussion was quite correct, except that the profile drag coefficient should refer to the wing only and not include the parasite drag of body, nacelles, etc. It can be shown that not only optimum speed, but also the optimum L/D figure is reached when the wing alone is flying at its maximum L/D value, and not the aeroplane as a whole. That seemingly paradoxical fact, which was already pointed out in Lanchester's " Aerodynamics," can be better understood if it is made clear that in departing from the orthodox conception of an aeroplane with constant wing area, a growing or shrinking wing is now considered, with all other operating conditions remaining constant.

Mr. Belart showed a table containing values of optimum speed and wing

loading for various well known aeroplanes, worked out on much the same lines as indicated in Mr. Vessey's paper. There is a very considerable variation of best wing loading according to the type of aircraft; so a figure of 207 lbs./sq. ft. is obtained for the Schneider Trophy racer, whereas the B.A.C. Drone ranges at 10 lbs./sq. ft. The power loading has a most marked influence on the value of optimum wing loading, but there are also other important factors, notably the influence of parasite drag. A comparison of the Short " Mercury " trans-Atlantic machine flying with full load at maximum power output and with reduced weight allowing for half of the fuel used and at cruising power output showed that this machine reaches, in both cases, very nearly its best wing loading, and there is no doubt that its wing was actually designed with a view to obtaining optimum conditions in level flight. In this case, it was evident how a reduction in wing loading for cruising conditions was counterbalanced by a corresponding increase in power loading, while a comparison of the " Mercury " with the Douglas D.C.2, which is of similar all-up weight, but is markedly below its best wing loading, showed the influence of parasite drag, which is higher for the " Mercury " as a float plane and causes, therefore, its best wing loading to occur at a lower value.

He asked whether Mr. Vessey had considered introducing into his calculations the " Aeroplane efficiency factor " as used in the U.S.A., to allow for different types of wing load distribution and interference as affecting the induced wing drag. This factor can conveniently be combined with the wing aspect ratio, which constitutes a design condition influencing the optimum wing loading. Aspect ratio proved to be, however, of less importance than power loading, parasite drag and operating altitude, but it assumed a greater importance for heavily loaded machines requiring low induced drag at high lift coefficients, such as short turning qualities of a fighter machine.

With regard to the flying wing, he said that Mr. Vessey had given rather high figures for the optimum wing loading. This problem could be approached from a somewhat different angle in taking a limiting speed of, say, 0.7 times the speed of sound and calculating the resulting wing and power loadings required. The limiting speed of about $v = 500$ m.p.h. (depending on altitude) would, according to data published by various authors, including a paper recently read by Lock before the Society, correspond about to the beginning of the compressibility burble on a normal wing at medium lift coefficients and would thus mark the point where the basic principles used for the optimum wing calculations would cease to hold good.

He showed a diagram based on a flying wing of a wing aspect ratio of $A = 7$ and a wing profile drag coefficient of $C_o = 0.007$. With the limiting speed given for various altitudes, the power loading required to fly at optimum conditions can be directly obtained from the speed equation :—

$$W/\text{T.H.P.} = (275/v)\,(\pi A/C_o)^{\frac{1}{4}}$$

and the corresponding optimum wing loading follows from

$$(W/S) = \tfrac{1}{2}\,\rho v^2\,(\pi A C_o)^{\frac{1}{4}}.$$

The diagram, in which speed, power loading required and optimum wing loading were plotted against altitude, showed, at sea level, a very high wing loading of about 300 lbs./sq. ft., but the values decrease rapidly with the drop in air density and at a stratospheric height of 50,000ft. the optimum wing loading is only about 30 lbs./sq. ft. At the same time, the thrust horse-power loading required, which is almost constant over the altitude range, is above 20 lbs./T.H.P., which is a surprisingly high value, comparing about with the power loading of the D.C.2 at 70 per cent. h.p. cruising output. It therefore seemed that the flying wing could soon be used with advantage at very great heights, allowing the attainment of speeds approaching the sound speed limit without excessive power expense.

In conclusion, Mr. Belart said that all his remarks were made with the assumption that take-off and landing problems bound up with high wing loadings were

solved. Mr. Vessey had shown in the second part of his paper how far this could be taken for granted at the present time.

Mr. P. W. S. BULMAN (*Fellow*): He expressed regret that an embargo had been placed on the discussion of the tricycle undercarriage, and suggested that statements made in the paper were the result of much misapprehension. Further, he had gained the impression that with the higher wing loadings of the future the problem of the take-off would be greater than that of landing. If that be so, it would appear that the provision of some form of arrester gear at aerodromes would be a very much simpler proposition than the supply of mechanism to assist the take-off.

Squadron Leader NORMAN (*Fellow*): It would be valuable to have an example, if that were possible, of the effect upon operating costs of the very advanced aspects of design that were dealt with in the paper. He would like to see the future possibilities of the aeroplane assessed in economic terms.

Those who had read the paper carefully would appreciate what the author had meant by the suggestion that concrete runways would not be of much economic value unless they were of very great size; but there might be some misapprehension on the part of those who read the paper hurriedly. Perhaps the author feared that runways of the size he wanted would not be available. One would like to know how he regarded the present standard aerodrome as laid down in the Maybury Report. Judging from the figures in the paper it would seem that at aerodromes giving, say, 1,200 yards run, concrete runways would be of very great value; and, of course, at places where long-range air traffic was envisaged, runs very much longer than that were being planned. Runs of up to 2,000 yards might be regarded as probable at air ports for which he had seen plans, and which were to be constructed in the future.

He asked for the author's ideas as to the value of providing concrete surfaces for only part of the take-off run. It was noticeable that at the new aerodrome at Berlin the runways were not planned for the whole length of take-off and landing runs; plans had been made for small circular concrete take-off areas, providing runs of only about 250 yards in all directions. By the construction of such comparatively short concrete runways a good deal of money could be saved, while the concrete surfaces would occur where they were most valuable from the point of view of aiding acceleration. Could Mr. Vessey indicate, either by a diagram or numerically, the relative importance of a low μ at different points along the take-off run?

Captain COURTNEY: He commended the paper for the valuable assistance it gave in the consideration of the problems raised therein from the strictly practical standpoint. He predicted that about three years hence, when they would be talking of loadings of 60lbs. per sq. ft. in much the same way as they talked of loadings of 20lbs. per sq. ft. to-day, Mr. Vessey's paper would be regarded as the first big gun fired in the attack on the long-range problem.

In regard to take-off, the question of acceleration must be considered in connection with distance. In other words, if plenty of distance were available, a machine did not need auxiliary power; only where distance became increasingly less did auxiliary power become increasingly necessary, until in the limit the catapult might have to be used.

Expressing the hope that the author would develop a good deal further some of the points dealt with in the paper, he said they could be developed in a number of different ways. For example, in Fig. 1 of the paper the question of optimum wing loading was dealt with, and presumably the method adopted was to increase the wing loading of a sample aeroplane by reducing the wing area. He, personally, had attempted to deal with the same general problem some time ago in a different way, *i.e.*, on the basis of a standard aeroplane of standard wing area he had tried to estimate the effects of increasing the wing loading, and had simply added power to maintain the induced drag at the original figure. Several quite useful diagrams of that nature could be produced to illustrate the

practical operation of the various types. There were many variables; but those interested in long-range air traffic would like to see the work extended on lines such as those pursued so far by Mr. Vessey.

Mr. P. NAZIR (*Associate Fellow*): Commenting on the statement, in the summary of the paper, that with the present type of flaps, the landing run restriction appeared to impose an upper limit of wing loading of about 30lbs. per sq. ft. for land planes, 35lbs. per sq. ft. for flying boats, and 40lbs. per sq. ft. for land planes with a front wheel undercarriage, he asked whether anyone could forecast what difference the three-wheel landing gear would make if applied with the cut slot and flap arrangement. He believed it would result in a surprisingly high wing loading.

Mr. W. E. GRAY: The paper referred to the initial rate of climb as being the quality enabling a machine to get away from an aerodrome at a safe height to clear obstacles. He had argued it with the Air Ministry for years, and ultimately they had relaxed the requirement of 400ft. per minute as the minimum rate of climb. The factor that mattered was the angle of climb and not the rate of climb, and he was surprised that rate of climb had been mentioned again in Mr. Vessey's paper. He had thought that it was dead and buried.

Mr. G. B. FENTON (*Associate Fellow*): It would appear that the question of high wing loading and take-off run is of vital importance in the case of an aircraft designed to operate from the deck of an aircraft carrier. Such aircraft are subject to severe restrictions on overall dimensions, and these restrictions, together with the modern requirements of high performance and load carrying capacity, necessitate the use of wing loadings at least as high as any used at the present time on other aircraft types. The deck operating aircraft, however, differs from other types in that the length of run to get off the deck must be kept down to the absolute minimum, and a pilot is faced with the two conflicting requirements of high wing loading and very short take-off run.

The use of flaps, and other high lift devices assists, of course, in the solution of the problem, but he would like to ask Mr. Vessey if he has given any consideration to the best method of using flaps to ensure the minimum take-off run.

In Fig. 7 of the paper curves of take-off run are shown with and without flaps, but no explanation is given as to how the flaps were used.

The usual method, he believed, is to use about 15° or 20° flap angle during the run, as full flap angle leads to a reduction in accelerating force outweighing the beneficial effect of the lower take-off speed. This technique applies to both high and low drag flaps, with possibly some difference in actual flap angle used.

The shortest run would be obtained if it were possible to accelerate with flaps right up till the speed was equal to the lowest possible take-off speed with flaps hard down, and then to lower the flaps instantaneously. This method, of course, is impracticable, but from the results of some rather rough calculations he had reached the conclusion that a substantial reduction in take-off run would be obtained if the flaps were lowered gradually from the start of the run in such a way that they were hard down at the instant of leaving the deck.

He would be glad to have Mr. Vessey's opinion on this point, as the technique appears to be capable of practical application, and, if resulting in a decrease in run, would help considerably toward making possible the application of high loadings to deck operating aircraft.

Mr. R. M. CLARKSON (*Associate Fellow, contributed*): He was much interested in Mr. Vessey's able exposition of a very important subject and in the ensuing discussion, and very pleased when he at last heard Dr. Lanchester's name mentioned in connection with the optimum speed—it is a pity he was not able to be present.

Could he say a word in favour of the use of span loading (weight/span^2, span being, of course, the equivalent monoplane span) in preference to wing surface loading? It seemed to him that span loading is a more important parameter than wing loading and is more representative of the " loading " of an aeroplane.

Wing loading only determines the take-off and landing speeds and to a certain extent the forward speed for max. angle of climb, all other departments of performance, if expressed in terms of wing loading, necessitate the inclusion of aspect ratio. Induced drag, however, being a function of span loading, the latter has much greater significance than wing loading; the power available for barrier climb after take-off is directly dependent upon it (for given h.p. available) and the other departments of performance determining barrier height (take-off speed, etc.) are indirectly related to it; ceiling, rate of climb, etc., are functions of it; and all questions relating to the optimum speed can be discussed in terms of span loading without reference to aspect ratio. Also span is of much greater structural significance than wing surface.

It has been found that for a number of varying types of monoplanes and biplanes, span loading is a better all round index of "take-off-over-the-screen-capability" than wing loading. It is interesting in this connection to note that wing surface loading does not appear in the standard method of aircraft performance calculation which is in general use throughout the U.S.A. (N.A.C.A. Technical Report No. 408), nor in a somewhat similar method of calculation developed in this country several years ago ("Aircraft Engineering," January, February, March, April, 1933). In both of these methods span loading is the parameter used, and its use follows naturally from theoretical considerations.

Figs. 5 and 6 are of much interest, but would not the difficulty of having to plot and explain curves 6 and 6a, and 7 and 7a have been obviated if the ordinate had been

Mean take-off thrust/max. take-off b.h.p.

instead of

Mean take-off thrust/cruising thrust?

He agreed with Mr. Vessey that generally the high altitude airscrew, on account of its greater diameter, is better conditioned for high take-off thrust, than the low altitude airscrew; but it is found that with the high speeds (say 375 m.p.h.) at high altitude now being talked about for Service aircraft, the combined effects of low temperature and large helix angle will necessitate a restriction of diameter in order to avoid tip speed losses at cruising speed; this restriction, whilst not affecting the cruising efficiency (because the high forward speed demands a diameter reduction), will naturally reduce the take-off thrust.

Reply to Discussion.

It appeared that he had disappointed a number of speakers by placing an embargo on the discussion of the three-wheel undercarriage, but his reason for this was that Squadron Leader Fraser would deal with it from the point of view of a pilot in a paper to be presented to the Society shortly, and it would be a pity to discuss the references to it in the present paper, which references were made largely from the theoretical point of view, before hearing Squadron Leader Fraser's remarks as a pilot. When both points of view had been stated there should be a much better discussion on the advantages and difficulties of the three-wheel undercarriage.

Dealing with the Chairman's question concerning increase of engine power and reduction of wing span, there was no doubt that difficulty would be experienced if progress continued on present lines. Increased power would necessitate larger diameter airscrews, which would be further increased if flight at high altitudes was required. The tendency to increase wing loadings would reduce the wing area and the span, so that the difficulty of obtaining airscrew clearance in multi-engined aircraft would soon become pressing. Some relief in airscrew diameter may be expected from the increase in cruising speed obtained by the higher power and by cleaning up, but the general trend will be towards larger diameter airscrews. The diameter of an airscrew may very approximately be expressed as

$$D^2 = \text{constant } (\text{b.h.p.}/\sigma S V)$$

where b.h.p. = cruising horse-power.

V = cruising speed.

σ = relative density.

S = airscrew solidity (or number of blades × blade width).

An increase in power in the same aeroplane will increase the speed approximately proportional to the cube root of the increase in power, and thus there will be an increase in airscrew diameter unless extensive cleaning up is done to further increase the speed. Similarly, with high altitude flight a reduction in density will cause an increase in speed somewhat less than the inverse cube root of the relative densities and an increase in diameter will again be required.

For flight at normal altitudes the reduction in wing area will seriously restrict the space available for engines and airscrews. A partial solution would be an increase in airscrew solidity by the use of four, or even six-bladed airscrews, but it would appear that the present trend will sooner or later force designers to some type of tandem arrangement. The reduction in wing chord, and therefore wing thickness, will make a low drag nacelle installation more difficult unless the flat type of engine which can be fitted within the wing contour is developed or considerably thicker wings are used. For high altitude flight the wing loadings will be lower and the difficulties less, except for the fact that larger diameter airscrews will be required.

For both cases a partial solution to the problem of large diameter airscrews could be obtained by designing the airscrews for a cruising efficiency slightly less than maximum, not as in the examples given in the paper by increasing diameter, but by reducing it. A reduction from optimum diameter of about 10 per cent. is possible with no appreciable effect on high speed performance, but the take-off thrust will of course be considerably reduced.

Major Penny had made a case for the very large flying boat with accelerated take-off, and there is no doubt that the flying boat could approach the level of cleanness of the land plane if the hull size were reduced by allowing for the alighting condition only. In general the hull of a flying boat is considerably larger than is required for the accommodation of the pay load, and this is particularly true of trans-Atlantic designs where the pay load is small and most of the fuel is carried in the wings. In addition, the normal hull is of a bad aerodynamic shape due to its design being dictated by take-off considerations and the necessity of obtaining adequate water clearance for the airscrews. As explained above, some reduction in airscrew diameter can be obtained by allowing a slight drop in cruising efficiency; the airscrews would be of comparatively high pitch and the reduction in cruising speed would be small. The reduction in thrust at low speeds, however, might be serious in the case of a trans Atlantic boat with comparatively high power loading, even if assisted take-off were used. A reasonably high rate of climb is desirable even in a flying boat, as it reduces danger due to the failure of one engine and permits of flight at a reasonably high altitude if required.

Dr. Lachmann had given the expression for maximum L/D which defines the speed for maximum range of a given aircraft. This speed is almost universally referred to as "economic speed," and the author has no knowledge of the use of optimum speed for this condition. The expression given by Dr. Lachmann for optimum speed in his written contribution is identical with the expression of Appendix I. Dr. Lachmann rather surprisingly objects to the use of "power loading" and "drag at 100ft. per second" in the expressions for optimum wing loading and speed. Power loading is now a well-established term in general use, and "parasite drag at 100ft. per second," far from being a "worn out conception," is a fundamental quantity obtained from the drag analysis or from wind tunnel tests. If required it can afterwards be converted to "parasite drag area," but the advantages to be gained are small. Dr. Lachmann and Mr. Belart both pointed out that the wing loadings given for the flying wing were high. The author's figures were obtained by assuming flight at present

operating altitudes and with power loadings that would give a normal take-off. The optimum wing loadings can then be correctly termed "enormous." The two speakers had pointed out that if the operational altitude is high the optimum wing loading comes within the bounds of possibility. It is not clear, however, to the author that the example given by Dr. Lachmann represents a practicable design as it is difficult to see how 15,000lb. of fuel, let alone pay load, can be carried in a flying wing of area 445 sq. ft., span 67 feet and mean chord 6½ feet.

The treatment of the flying wing in the paper was admittedly inadequate. Normal aeroplanes were being considered and the flying wing was only introduced to illustrate the interesting point that the optimum speed was the same at all altitudes. Dr. Lachmann had stated that it is more economical to add a fuselage if it is found to be impossible to stow the load in the wing. This is certainly true, and the effect will then be that the optimum speed will increase with altitude instead of being constant as with the true flying wing.

Dr. Roxbee Cox raised the question of variation of structure weight with wing loading and aspect ratio. This had only briefly been mentioned in the paper as one of the important variables which was often neglected in aerodynamic treatments. A simple treatment based on bending loads only is sometimes used for quick calculation, but may be very misleading as with modern aircraft a large proportion of the wing weight is caused by the torsion cases and by the necessity for providing adequate stiffness to avoid "flutter" and divergence. Dr. Roxbee Cox argued from the fact that the density remaining constant, the wing loading would increase with the size of the aircraft. The same conclusion could be reached by considering structure weight. For the same wing loading a simple treatment showed that the structure weight percentage increased with size, while a more refined examination by a method due to Dr. Roxbee Cox himself agreed with this but gave a more rapid increase. Thus for a given wing loading the larger aircraft were at a disadvantage, and if any considerable increase in size were contemplated it would only result in economic aircraft if the wing loading were also increased so as to obtain some relief in structure weight. Following the treatment of the paper the same result might also be expected, for the large aircraft might reasonably be assumed to be cleaner than the small one, due to the decreased effect of such necessary excrescences as pilots' windscreens and to the burying of the engines in the wing. This greater cleanness would force up the optimum wing loading. The author did not agree that the paper showed that so long as the present form of aircraft were retained we should soon reach a limit in wing loading beyond which it was not worth going. It would appear that the demand for higher performance would improve cleanness and power loadings so that the optimum wing loading would continually increase. In stating that the take-off loading of a normal flying boat might be higher than the alighting value the author was considering large flying boats on a well-organised commercial service where the take-off would be in sheltered water, but the landing, in the case of an emergency, would have to be safe in reasonably rough water.

Dr. Roxbee Cox advocated the use of low aspect ratio, but the author did not altogether agree with this view. Admittedly a reduction in A.R. would lead to a reduction in structure weight and therefore in size, but he was not satisfied that the smaller aeroplane would travel faster. As the chord of the wing was increased the body-wing interference drag would almost certainly be increased and a much higher proportion of the wing would be in the fuselage and nacelle interference region and also in the slipstream which had been shown to cause a considerable increase in wing drag. By using a high A.R. a large proportion of the wing area was removed from the interference region and the gain was thought to outweigh the increase in structure weight as long as aspect ratios of 8 or 9 were not exceeded. It was rather disappointing that no advocates of high A.R. were present to give their views, for there were obviously several designers in this country who pinned their faith to aspect

ratios of the order of 8 to 10 just as there were others who seldom exceeded 6 in their designs.

Dr. Roxbee Cox and Dr. Townend had both asked about the effect of inclining the airscrew thrust downwards. Although this might appear to be a case of " lifting oneself by one's boot straps," a detailed examination, say, on the lines suggested by Mr. Stafford* showed that a real advantage might be obtained. The downward inclination used was small, of the order of 3 to 5 degrees, so that at take-off there would still be an upward component of the thrust. With the thrust line acting along the wing chord there would be a considerable increase in lift due to the extra velocity in the slipstream, but there would also be a reduction in the effective angle of incidence due to the combination of the forward speed and the slipstream velocity. By inclining the airscrews downwards the reduction in effective angle of incidence was reduced and the nett gain in effective C_L at take-off was considerable.

Mr. Hollis Williams had rather misunderstood his remarks regarding concrete runways. The author had shown that from the point of view of change in coefficient of friction the concrete runway only became of value when long runs were allowed, but he had qualified his statement by introducing the effect of weather and tyre loading in almost the same terms as Mr. Hollis Williams.

Mr. Belart had made a very useful addition to the discussion and had cleared up the point mentioned by Dr. Lachmann with regard to the optimum wing loading. The examples he gave showed that typical present day high performance aircraft were working below optimum wing loading and that a considerable advantage could be gained if the take-off and landing limitations could be overcome. The American " aeroplane efficiency factor " could be used in the treatment quite simply, and actually a similar factor was used in the wing drag equation :—

$$C_D = (a + bC_L^2).$$

The induced drag term bC_L^2 being calculated from the effective aspect ratio rather than the geometrical. Mr. Belart's remarks with regard to the flying wing were agreed and had already been dealt with.

Mr. Bulman's remarks with regard to take-off and landing were not understood. The present developments tended to show that landing rather than take-off would become the problem of the future, except perhaps in very long range aircraft where a considerable relief in wing loading at landing was given by fuel consumption. Aerodrome arrester gears might be of use for a few specific types, but as they could not cater for a forced landing it would be very unwise to rely generally on any such device.

Squadron Leader Norman dealt with aerodrome runways. The author agreed that concrete runways of the order of 1,200 yards would be of considerable value, while if 2,000 yards could be allowed with a clear take-off path he considered that the necessity for any form of assisted take-off for land planes would be postponed for some considerable time. With regard to short lengths of concrete runway, the German system described was probably designed mainly to assist ground handling and to avoid damage to the aerodrome surface at the points where it was most used. However, a partial runway of this type would for normal aircraft give almost as short a take-off run as a complete concrete runway of the same total length and would lead to a considerable economy in construction. For normal aircraft it was desirable to use concrete for the first part of the run, but a case might be made for the use of concrete in the latter portion of the run of a modern long range aircraft if a complete concrete runway could not be provided. This result might be thought to be surprising, but was caused by the fact that with modern airscrews a high static thrust was obtained which dropped rather rapidly as the speed increased. This meant that the acceleration in the latter part of the run was low, and if some allowance was

* " Aircraft Performance Estimation " by C. O. Vernon, Student. J.R. Ae. Soc., Aug., 1937.

made for the increase in ground friction with speed, due to energy absorption by the undercarriage caused by bumps, it was found that in certain cases of heavily loaded aircraft the total run was shorter if the initial half of the run were on grass and the latter on concrete rather than vice versa. The distance would, however, be appreciably greater than if the whole runway were of concrete.

Captain Courtney predicted that loadings of 60lb. per sq. ft. would be commonplace in about three years' time, and although the author put the time rather more ahead than that he was convinced that it would not be long before loadings of that order were in use.

Mr. Nazir had asked what increase in loading could be allowed by the use of the " cut slot and flap." That, of course, depended upon the lift and drag characteristics that could be obtained, and the author had so far seen only the results of wind tunnel tests at a low Reynolds number, which, although they appeared to offer the promise of an appreciable assistance in take-off, could not be used to give a reliable estimate.

Mr. Gray objected to the use of " initial rate of climb " as an indication of the ability of an aeroplane to clear obstacles when taking off. In the initial stages of the take-off, angle of climb was, of course, much more important than rate of climb, and that point had not been neglected as could be seen by the reference to " distance to clear a barrier." It should, of course, have been made more explicit. Apart from take-off, however, rate of climb was the determining factor in cases such as one engine flight, cruising at high altitudes and so on.

Dealing with Mr. Fenton's written contribution, it was agreed that the difficulty of obtaining good take-off from the deck of a ship was considerable if the aircraft had at the same time to give a high performance. Full use of V.P. airscrews and flaps was of assistance, but any further advantage that might be obtained would be of considerable value. The point raised as to the correct method of using flaps was of considerable interest, and the author agreed that a controlled rate of lowering the flaps during the take-off run would be of value, although to be of general use the controlling device must be automatic in action. Mr. Fenton cast doubt on the possibility of a sudden lowering of the flaps at the end of the run. There is no doubt that this would give the best results, and it is believed that this method has been tried in America, although the author has no knowledge of the operating mechanism or of the results that were obtained.

Mr. Clarkson in his written contribution stresses the importance of span loading. It is agreed that this is an important parameter which may be used without reference to wing loading in most performance calculations. For take-off, however, wing loading is more important than span loading, and as the major portion of the paper is concerned with take-off, wing loading and aspect ratio were used rather than span loading. Span loading can be used in the expression for optimum loading, but does not lead to any simplification. In plotting Figs. 5 and 6 the author first considered the method suggested, using thrust/horsepower instead of thrust/cruising thrust, but abandoned it as it did not give a true indication of thrust. Thus, if the take-off power be increased, the thrust/horsepower will probably drop, although the actual take-off thrust may increase. Thus the method used is to be preferred as it gives a true comparison of actual take-off thrust.

The effect of tip speed on airscrew diameter causing a restriction in the diameter of high altitude, high performance aircraft is recognised, and as stated by Mr. Clarkson it may necessitate a reduction in airscrew diameter, thus giving a poor take-off. Another and better method of avoiding high tip speed is to reduce the gear ratio; this will necessitate a larger diameter airscrew, but the net effect will be a reduction in tip speed. There will then be an appreciable gain instead of a loss in take-off thrust.

The 627th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, Westminster, London, S.W.1, on Thursday, December 2nd, 1937, at which a paper on "High Wing Loading and Some of Its Problems from the Pilot's Point of View," by Squadron Leader H. P. Fraser, A.F.C., B.A., A.F.R.Ae.S., R.A.F., was read and discussed. In the Chair: Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President.

The CHAIRMAN: In introducing the lecturer, he drew attention to his high academic and Air Force distinctions. He took the Mechanical Science Tripos at Cambridge in 1929, and while at Cambridge he was an Officer in the R.A.F. Reserve and a member of the University Air Squadron. He was Commissioned in the R.A.F. in August, 1929, served in Army Co-Operation Squadrons, his service including a short period in India, and specialised in engineering at Henlow in 1933-34. Since then he had been engaged at the Royal Aircraft Establishment on experimental flying. He was awarded the Air Force Cross and was elected an *Associate Fellow* of the Royal Aeronautical Society. The next obvious step would be his election to Fellowship.

HIGH WING LOADING AND SOME OF ITS PROBLEMS FROM THE PILOT'S POINT OF VIEW.

By Squadron Leader H. P. FRASER, A.F.C., B.A., A.F.R.Ae.S., R.A.F.

INTRODUCTION.

It is indeed a very great honour for so new a member to be accorded the privilege of reading a paper before the Royal Aeronautical Society, and I would like to express my sincere thanks to the President and the Council of the Society for the invitation extended to me.

We have heard from designers and experts in all branches of aeronautics what problems confront them and how they propose to solve them. I am going to discuss, from the point of view of a pilot, some of the problems that seem to me to arise from high performance and increased wing loadings, and to indicate what appear to me to be possible solutions. I propose to consider these problems under five headings:—

(1) Take-off.
(2) Irreversible Aileron Control.
(3) The Approach.
(4) Flattening Out
(5) Touching Down.

TAKE-OFF.

Taking off in the new types of aeroplanes is a comparatively simple matter. Flaps, variable pitch airscrews, trimming tabs and boost controls are all set at the optimum position and, having taxied to the edge of the aerodrome, the throttles are opened and the aeroplane is taken off. No great increase in skill is required. At the most a new, but not more difficult, technique has to be learnt. The whole of the take-off problem has really been solved by the designer

beforehand or the aeroplane would not be flying. Thus the actual act of taking off does not, in itself, present any new difficulties from the pilot's point of view, and as a pilot I have nothing to say regarding the design, types, and combinations of devices to be employed for unassisted take-off at high wing loadings.

What is, however, beginning to worry me about the take-off is that, if wing loadings get much higher, calculations have shown that the design of flaps and variable area wings will have to be considered from the point of view of take-off only. Landings will have to be made with a wing flap combination which is without some of the characteristics that make for ease of landing, because the means by which such characteristics are obtained are detrimental to the take-off. Since landing is far more difficult from the pilot's point of view I do not want to sacrifice ease of landing in order to get the aeroplane into the air. I think, and I sincerely hope, that the not too distant future will bring a solution which will make it unnecessary to sacrifice ease of landing for good take-off, and which will simplify the task of the designer as well as of the pilot.

Long range with heavy load is going to be an essential in the near future. If we are not going to be left behind in this respect wing loadings at take-off will soon have to go up to a value at which it will no longer be possible to think about unassisted take-off if aerodromes are to be kept within practical limits of size. Assisted take-off will become essential. I feel that, rather than concentrate too much on wing surface devices for getting highly loaded aeroplanes into the air, it would be more profitable to seek a simple solution to the assisted take-off problem. I should be particularly happy to see a simple method of assisted take-off evolved, because then the design of wing surface controls need only be considered in relation to landing, which is the pilot's greatest problem and which cannot be "assisted." A discussion of possible simple, and they must be simple, methods of assisting aeroplanes into the air is outside the scope of this paper. Experts are at work on this problem and I feel sure that a simple solution will soon be found.

Irreversible Aileron Control.

A considerable amount of thought and research is being devoted to finding a new form of lateral control owing to certain defects in the present form. Though there are several very promising types, no new form of lateral control has, to my knowledge, yet reached a stage where it seems likely to displace the aileron in the near future. It is not improbable, therefore, that as speeds increase it may become necessary to solve the wing aileron flutter problem by recourse to irreversible ailerons. Such a control has been viewed with alarm by some pilots. As I have had an opportunity of trying out such a control I propose to discuss it and examine some of the criticisms that have been levelled against it.

It should be made perfectly clear at the outset exactly what is meant by irreversibility in this particular connection. The means by which irreversibility is obtained is illustrated in principle in Fig. 1. Suppose it is desired to move the aileron rod (N) from right to left. The control column is operated so as to move the piston (A) from right to left. As the cylinder (B) is fixed by the pawls F_1 and F_2 engaged in the racks H_1 and H_2, the first movement of the piston (A) forces the roller K_2 down along the inclined surface Z_2 which disengages the pawl F_2 from the rack H_2. Further movement of the piston (A) to the left now moves the whole cylinder to the left as well, the force being transmitted through the now fully compressed spring L_2. During movements to the left the pawl F_1 rides over the teeth on the rack H_1. If, however, an excessive load comes on the aileron tending to overcome the pressure the pilot is applying on the control, movement of the cylinder to the right is prevented by the leaf spring (G_1) forcing the pawl (F_1) into a tooth on rack (H_1). Thus the aileron cannot move in a direction opposite to that of the direction of the force applied to the control column. Nor can the aileron, if overbalanced for example, force the control column to move faster than the pilot wishes, because, as soon as it tries to, the

cylinder leads the piston, thus allowing the respective pawl to engage a tooth in the rack again. Irreversibility obtained by this principle entails a small (and it can be made quite inappreciable) amount of back lash at the control column. It should not, however, make the control any heavier to operate than without the irreversible link. Any irreversible system which increases the control forces

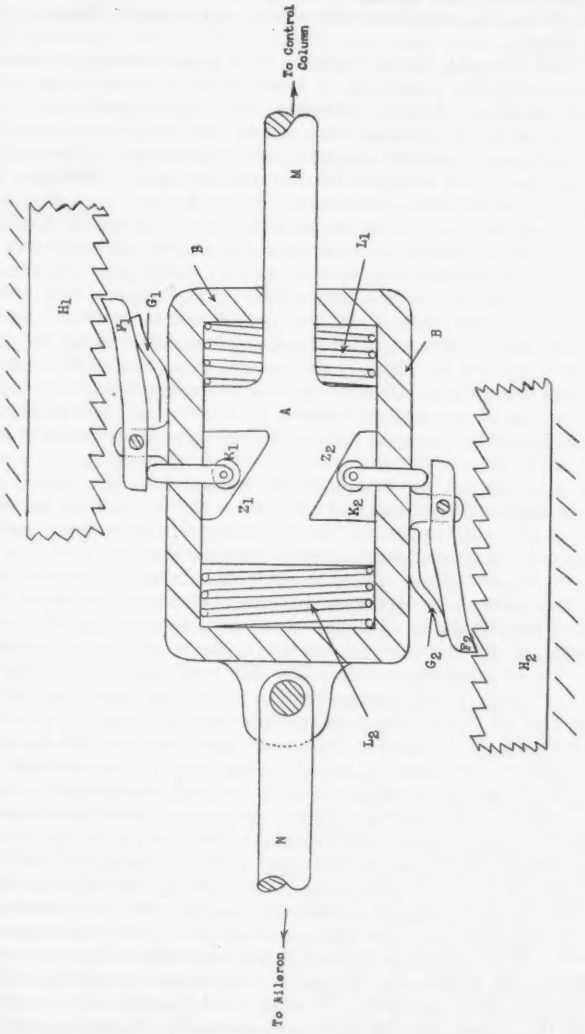


FIG. 1.

Diagram showing a principle by which irreversibility can be obtained in a flying control.

by more than a few per cent. cannot be tolerated. For all practical purposes the only difference between irreversible and self-centring ailerons is that in the first case the control column remains where it is put, while in the second it returns to the neutral position on being released after displacement. The actual force displacement diagram is the same to within a few per cent. It is hoped

that any idea that irreversible controls entail much larger operating forces than are experienced on normal controls is dispelled.

The question now arises as to whether irreversible ailerons are acceptable from the point of view of flying technique, and whether their presence introduces any dangers. This question is probably best answered by considering some of the criticisms commonly levelled against them.

It has often been said that though irreversible ailerons are acceptable for flying in clear air they will introduce difficulties, and possibly dangers, in blind flying and night flying.

When flying blind inherent lateral stability is a great advantage because the aeroplane will automatically return to a level position after being disturbed slightly in the rolling plane. Except, therefore, for large disturbances in roll the pilot need not worry about the aileron control and can concentrate upon keeping the aeroplane straight and maintaining the correct airspeed. Considering first an aeroplane which has good inherent lateral stability, it is clear that the only effect of introducing irreversible aileron control will be that the pilot will have to return the control column to the central position after each lateral displacement. Thus provided the control column is kept central laterally the pilot will be able to take advantage of the aeroplane's inherent lateral stability to the same extent as with self-centring ailerons. It has been argued that the pilot may not be able to keep the control column exactly in the centre unless he has some mark, and that a mark is undesirable because it adds yet another thing to the many the pilot has already to watch. But, if the aeroplane is inherently stable to the degree that enables the pilot to allow it to look after itself laterally, any slight error in the positioning of the control column (laterally) will not produce a continuous roll. It will merely have the effect of putting a wing down a degree or so, which is of small practical consequence. It is contended, therefore, that non-self-centring ailerons, on an aeroplane with good inherent lateral stability, do not make the aeroplane dangerous to fly blind nor do they add to the difficulties of the pilot, who is still able to control the aeroplane on the elevator and rudder, using the ailerons only to correct large lateral disturbances.

Turning next to the aeroplane which is neutrally stable or unstable laterally: on this class of aeroplane it is necessary for the pilot to correct each and every disturbance in the lateral plane. Furthermore, on an aeroplane of this class a slight displacement of the control column from the exact central position will produce a slow rate of continuous roll. The effect of non-self-centring ailerons will be twofold. Firstly it will mean that the pilot will have to exert a force both to displace and to return the control column. The extent to which this imposes an extra strain on the pilot is dependent upon the time the control has to be held in the displaced condition to get the wing up. If the measure of strain on the pilot is taken as the product of force exerted multiplied by time, it is clear that the " strain " to correct a bump with a self-centring control is the average force during displacement multiplied by the time, plus the force needed to maintain the control column in its displaced position multiplied by the time it has to be displaced to raise the wing; while that for a non-self-centring control is the force times the time for the displacement, plus the force times the time for the return of the control. No force is needed to keep the control in the displaced position. From this it is evident that a non-self-centring aileron control may greatly lessen the strain on the pilot of a large aeroplane with a slow response. As the size of the aeroplane decreases and the responsiveness increases, the lessening of the strain on the pilot will gradually disappear until, on the interceptor and possibly the single engine bomber types, there might be a small increase in strain. Secondly, there will be a tendency towards a small lateral oscillation owing to the pilot not being able to find the exact neutral position of the stick. This will impose a small additional strain. The nett effect is the algebraic sum of the above two and indicates that on the smaller aeroplanes of this class with quick lateral response non-self-centring ailerons may impose some

additional strain—though not dangerous; while on the larger aeroplanes of the class, with relatively slow lateral response, non-self-centring ailerons are likely to prove advantageous.

It is now necessary to consider aeroplanes with a high degree of directional stability, since nearly all modern types possess this characteristic. The important result of this is that, if the aeroplane is banked 10° or 15° against the turn, full rudder will not succeed in making the aeroplane turn in the desired direction until the wings are brought level (and even then the resultant flat turn may be too slow for practical use). The result is that even with an aeroplane that is fairly stable laterally it is not possible to allow the aeroplane to look after itself in the rolling plane, since any displacement in that plane produces much bigger wanderings in the yawing plane than heretofore, and these wanderings are now more difficult to correct by rudder alone. If, however, the aeroplane possesses but a low degree of lateral stability—as is usually the case on modern monoplanes—the pilot is absolutely obliged to control the aeroplane in the rolling plane in order to make it turn at all. In fact, the situation is now reversed and by far the least tiring, if not the only way of flying blind, is to keep the rudder fixed central and fly on ailerons and elevator in the same way that the direct control autogiro is flown. Since, whether or not the aeroplane is inherently stable laterally, it is necessary consciously to keep the aeroplane level laterally by use of the ailerons, instead of assuming it will keep itself level, and since most aeroplanes are now fitted with good gyro lateral level indicators, there is no justification for supposing that a non-self-centring aileron control constitutes a danger for night flying or blind flying. The only valid criticisms are the two which have been dealt with above, namely, the possibility of a small additional strain in aeroplanes with a quick lateral response, and the tendency to a small lateral wander about the level position.

It has been objected that a non-self-centring control may lead to a wing touching the ground during taking off at night. It is, however, considered that this is not much more likely than with self-centring ailerons. Firstly, ailerons are not self-centring until a reasonable speed is reached, so it is possible for the pilot to hold even self-centring ailerons as much displaced from the neutral position as non-self-centring ailerons without feeling it. Secondly, with the ailerons displaced that small amount it is not thought that a wing would drop sufficiently to touch the ground before take-off. What danger there is is not much greater, if at all, than with self-centring ailerons.

Mention has been made that when the lateral response is quick a non-self-centring aileron control throws a slight additional strain on the pilot. Aeroplanes that come in this category may be taken to be those that have fixed front guns, that is, fighters and single engine bombers. On these aeroplanes, quite apart from making it slightly less tiring to fly blind, a self-centring control would probably be preferable for keeping the sights on the target owing to the elimination of any tendency for a slight hunt about the mean position. One way of overcoming the disadvantages of irreversible controls on these types of aeroplanes would be to retain the irreversible property, but to make the control self-centring in the following manner. Some ailerons are extremely light for small movements and are overbalanced for large movements, the force required to move them does not alter much with speed and they are very effective.

If a well designed irreversible mechanism were fitted to such ailerons it would be possible to give them an artificial " feel " and make them self-centring by inserting a spring and cam arrangement on the control column side of the irreversible link. Several aeroplanes have such spring self-centring devices even now. Here is a possible method of having self-centring irreversible controls, and these could be fitted to those classes of aeroplane which have been stated as being undesirable to fit with non-self-centring aileron controls.

Incidentally, it should be made perfectly clear that the feel of self-centring (spring) irreversible controls is an artificial feel, and is, therefore, not an

indication of the speed of the aircraft. This, however, does not matter, since the feel of the ailerons at the correct gliding speed and at a few m.p.h. above the stall is not sufficiently different on modern aeroplanes to make it a means of finding and maintaining the correct gliding speed. It is the self-centring property that is needed and not the ability to feel the ailerons.

Sometimes for one reaon or another an aeroplane will fly "one wing low." On a long flight this is most tiring and irritating for the pilot, especially on a large aeroplane. Irreversibility relieves the pilot of the strain of having to hold the control displaced from central, and avoids the necessity for a lateral trimming device.

THE APPROACH.

Before discussing the approach and landing an explanation of the terms used is necessary. Fig. 2 illustrates the meaning of the terms approach, flattening out, float, touch down and landing run. The "*basic gliding speed*" is taken as the speed necessary in an engine off glide to make a no float landing. The "*basic gliding angle*" is taken as the angle of the flight path relative to the air when gliding engine off at the basic gliding speed. The maximum gliding angle is the steepest gliding angle of which the aeroplane is capable without increasing the basic gliding speed. Whenever increase of gliding angle is mentioned no increase of speed is assumed.

If an aeroplane is known to be able to take off over an obstacle of a given height in a given distance, it is not unreasonable to expect an average pilot to

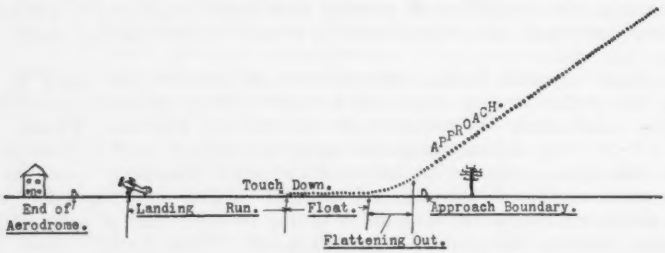


FIG. 2.

Diagram showing the various stages of a landing.

succeed in getting the aeroplane off over the obstacle in just a little more than the given distance. On the other hand, if in theory an aeroplane can come to rest after landing over an obstacle of a given height in a given distance, it is most unreasonable to expect an average pilot to be able to land the aeroplane over such an obstacle in just a little more than the prescribed distance, especially if the obstacle be a brick wall with another one facing it at the end of the allowed run.

The point I wish to make is that in the take-off the skill of the pilot does not count for much. The designer assumes that the pilot is sufficiently skilful to taxi to the edge of the aerodrome before beginning to take-off and clearly he has every justification for such an assumption. When, however, an aeroplane is designed to land in a certain horizontal distance after passing over an obstacle of a certain height the designer is assuming that the aeroplane is going to be flying at a specified speed as it passes just a foot or two above the obstacle. It is the pilot who has to use skill and judgment to ensure that the designer's assumption is correct. If not, the aeroplane will not be landed within the prescribed area. The problem of landing an aeroplane is, therefore, one in which both designer and pilot must work together. The pilot must help the designer by saying quite definitely whether he (the pilot) has been given sufficient control

of gliding speed and gliding angle during the approach for there to be a reasonable chance of passing over the aerodrome boundary at the correct speed and height, so as to fulfil the designer's expectations of the aeroplane coming to rest within the calculated distance of the aerodrome approach boundary.

I think it is remarkable that the new types of aeroplanes are not more difficult to approach and land when it is realised what a big jump there has been in wing loadings and, as a pilot, I feel I owe a very great deal to designers for making this possible. It has to be admitted, however, that the judgment of the approach has become much more difficult; so difficult, in fact, that a new technique involving the use of the engine has had to be adopted for landing on an aerodrome, while it has been decided that a successful forced landing is well nigh impossible to make, and that to reduce the landing run aeroplanes are to be forced landed with the undercarriage raised.

I do not believe that it is impossible to make the judgment of the approach easier, and to give back to the pilot some of the control over the speed and angle of the approach that was possible on the aeroplanes that are now being displaced by new types.

So as to avoid confusion let us consider the theoretical aspect first and then discuss the practical aspect to see how far it may be possible to make the actual aeroplane conform to the ideal.

It would be appropriate here to consider the difference between a flat and a steep basic gliding angle from the point of view of the approach. The main objections to a flat glide are:—

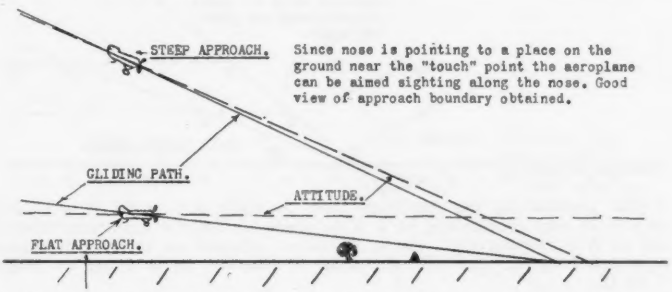

STEEP APPROACH.
Since nose is pointing to a place on the ground near the "touch" point the aeroplane can be aimed sighting along the nose. Good view of approach boundary obtained.
GLIDING PATH.
ATTITUDE.
FLAT APPROACH.
Position of nose no indication of where " touch " likely to occur. Nose may often obscure " touch " point.

FIG. 3.

Difference in the judgment of the approach between a steep and a flat glide.

(*a*) It usually means that the pilot's view forward is bad, making it hard to judge height and distance and come in low over obstacles.

(*b*) It means that a small error in speed will make the aeroplane touch down a long way from the desired point.

(*c*) It similarly means that a small error in the judgment of height, though the speed may be kept correct, will make the aeroplane touch down a long way from the desired point.

(*d*) In order to prevent a long float causing the landing area to be overshot the gliding speed has to be kept as near the stalling speed as possible. Thus there is a danger of stalling or sinking badly just before reaching the approach boundary when trying to land short, as is usually necessary in a forced landing.

(*e*) In order to touch down near the approach boundary the aeroplane has to be brought in very low over obstacles. This coupled with need for gliding

near the stall makes a landing—particularly a forced landing—extremely critical and demands an accuracy of judgment only likely to be found in a few exceptional pilots.

(*f*) The direction in which the nose is pointing gives no indication of where the aeroplane is likely to touch the ground. (See Fig. 3.)

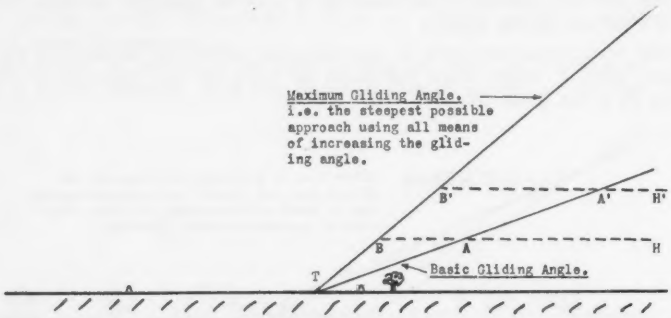
A steep basic glide on the other hand has the following advantages:—

(*a*) It gives a greatly improved view—the aerodrome and its surroundings being seen more in plan than in side elevation—which makes it easier to judge height and distance.

(*b*) It allows a greater error in judgment of height and speed to land within a given distance of a fixed point.

(*c*) It allows, in fact, it demands from consideration of flattening out, a higher speed in the glide relative to the stalling speed, and consequently lessens the chance of loss of control in gusts or inadvertent stalling.

(*d*) It allows a pilot to come in over obstacles at a safe height and still get into the landing area. This coupled with (*c*) above adds greatly to safety during the last and critical stages of the approach and gives a pilot greatly increased confidence.



A pilot approaching the aerodrome from the right at a height H or H′ will be able to land successfully at T if he closes his throttle anywhere between AB or A′B′ respectively. He is, therefore, allowed an error of judgment represented by AB or A′B′ according to whether he is flying at height H or H′.

FIG. 4.

Approach diagram for "overshoot" technique.

(*e*) It usually means that the attitude of the aeroplane is nearly co-incident with the gliding path and, therefore, within limits, the aeroplane will touch the ground somewhere near the point at which the nose is pointing. This does in fact give the pilot a crude form of sight, which shows him roughly whether he is overshooting, undershooting or is just right. (See Fig. 3.)

It is clear from this that an aeroplane is more likely to cross the approach boundary at the correct height and speed if the basic gliding angle is steep. But even in a steep glide judgment is not exact, and allowance has to be made for wind speeds and wind gradients. In the past a pilot was taught to close his throttle at a point where, making allowance for wind strength, he was confident that he would overshoot the approach boundary if he glided at the basic gliding angle of the aeroplane. As he then proceeded to glide towards the aerodrome, the nearer he approached it the more accurately was he able to judge the amount by which he was overshooting. It was then within his power to reduce the amount of overshooting by sideslipping, or by crabbing the aeroplane. Clearly there was a limit to the amount of overshooting he could correct by these means and a certain degree of accuracy was needed in the selection of the point at which to

close the throttle, or the means of steepening the glide would be insufficient for him to redeem his error of judgment.

Referring to Fig. 4, TAA' is the basic gliding angle (it is assumed that there is no wind), TBB' is the line before which the throttle must be closed if, using all available means of increasing the gliding angle beyond the basic, the pilot is to touch down without overshooting the point T. Thus for any height H or H' there are two points A and B, and A' and B' respectively, between which the pilot must close his throttle in order to land at the point T. After a little practice

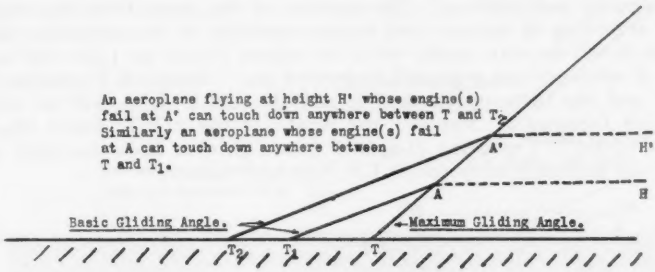

An aeroplane flying at height H' whose engine(s) fail at A' can touch down anywhere between T and T2.
Similarly an aeroplane whose engine(s) fail at A can touch down anywhere between T and T1.
A'
H'
A
H
Basic Gliding Angle.
Maximum Gliding Angle.
T2
T1
T

FIG. 5.

Approach diagram for forced landing.

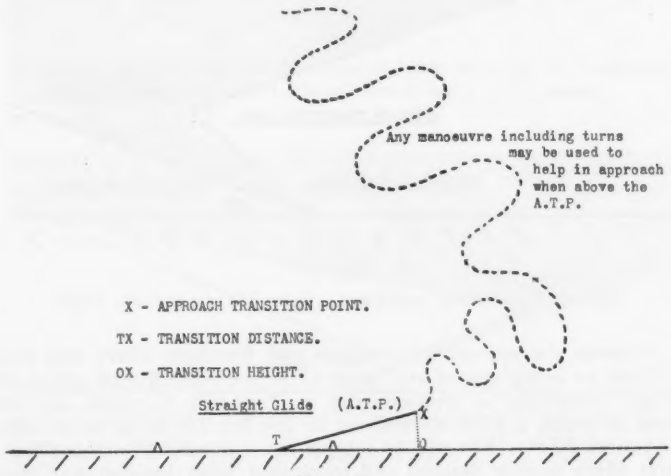

Any manoeuvre including turns may be used to help in approach when above the A.T.P.
X - APPROACH TRANSITION POINT.
TX - TRANSITION DISTANCE.
OX - TRANSITION HEIGHT.
Straight Glide (A.T.P.)
X
T
O

FIG. 6.

Diagram illustrating the two phases of the approach.

the average pilot had a reasonable chance of being able to do this (even on some of the large twin-engine aircraft), as the absolute values of the distances AB and $A'B'$ were so large as to call for but fair judgment.

It will be noticed that the whole of the approach is made without the engine. The principle is that the throttles are not closed until the pilot is certain he will overshoot the approach boundary and then, during the glide, as the magnitude of the overshooting can be more accurately seen, it is reduced by increasing the gliding angle. This technique will be referred to as the " overshoot technique." It can easily be seen that the overshoot technique is equally effective for landing

on an aerodrome or making a forced landing with the slight difference in the latter case that the point in air is fixed by the failure of the engine and the point on the ground is arbitrary within the limits TT_2 for height H' and TT_1 for height H (see Fig. 5); TT_2 is equal to $A'B'$ of Fig. 4 and TT_1 is equal to AB.

The analysis must be carried one stage further if we are to be able to appreciate the problems arising from increased wing loadings.

There is a point during the approach (Fig. 6) beyond which the glide has to be straight; before it " S " turns, stalled turns and almost any manœuvre may be used, but after it the only means of steepening the glide that are permissible are side slipping and crabbing. The distance of this point from the touch point will vary according to the size and manœuvreability of the aeroplane; for some aeroplanes it will be very small, while for others it may be 1,000 feet or more. For ease of reference this point will be termed the " *Approach Transition Point* " (A.T.P.) and the distance between it and the touch point will be called the " *Transition Distance.*" Similarly the height of the A.P.T. above the ground will be called the " *Transition Height* " (see Fig. 6). Both diagrams 4 and 5 represent the approach after the A.T.P. has been passed.

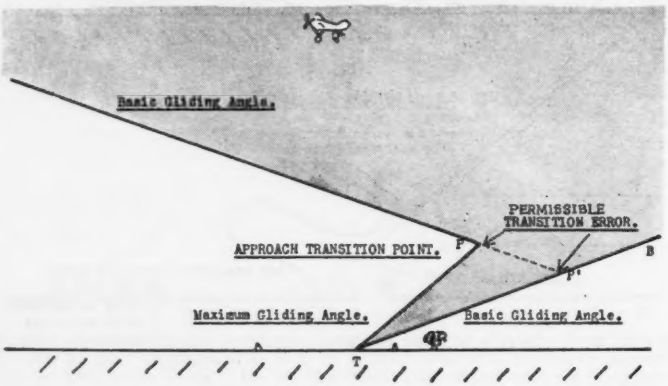


FIG. 7.

Approach diagram extended above the transition point.

Fig. 7 extends the approach to heights and distances above and beyond the A.T.P. Thus an aeroplane at any point Q in the shaded area which wishes to land (either voluntarily or involuntarily) at T is able to reach, and should be manœuvred to reach, a point somewhere on the line PP' so as to be able to pass down the funnel PTP'. PP' will be termed the " *Permissible Transition Error.*"

The first effect of new designs and increasing wing loading was that it was soon realised that basic gliding angles were becoming much flatter and introducing the many objections to a flat gliding angle. In short it was soon discovered that it would be quite impossible for the average pilot to land such aeroplanes in existing aerodromes. As a remedy flaps had to be fitted. The primary object of the flaps was to reduce the stalling speed, and so the basic gliding speed and the length of the landing run. All flaps, on some aeroplanes more than others, besides reducing the stalling speed also increased the basic gliding angle. I think most pilots will agree that it was the increase in the basic gliding angle with its attendant advantages that was appreciated far more than the actual reduction in the stalling speed. It did make the approach a little easier, and did allow a *small* error in the judgment of speed and height without hopelessly overshooting the aerodrome.

The second effect of new designs is that on many types the ability to sideslip or crab the aeroplane has almost entirely disappeared and therefore the maximum gliding angle has become almost co-incident with the basic gliding angle. (See Fig. 8.)

The third effect of the new designs is that the transition distance and height have very greatly increased owing to it being impossible to continue to use " S " turns anywhere as near the approach boundary as heretofore. On some of the larger new types the transition distance is really very great. (See Fig. 9.)

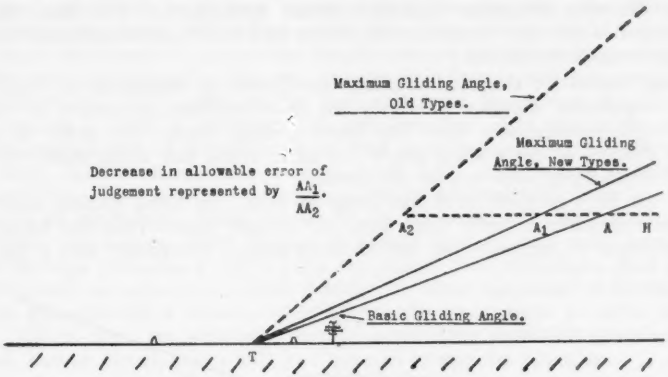


FIG. 8.

Diagram illustrating the increase in the accuracy of judgment required in order to touch down on a given point.

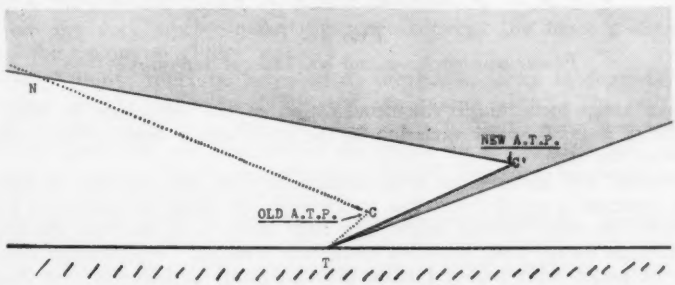


FIG. 9.

Comparison between old and new approach diagrams.

It should be noted in Fig. 9 that whereas *NC* is the basic gliding angle, *NC'* is less than the basic gliding angle, as the flaps, and undercarriage for that matter, need not be lowered before the A.T.P.

Referring to Fig. 8, whereas, when the allowable error of judgment was AA_2 the average pilot was able to land at or very near *T*, with the allowable error cut down to AA_1 it has proved quite beyond his capacity. A new technique has had to be adopted for a pilot, who is sure he is past the basic gliding angle line, is almost certain to have crossed maximum gliding angle line and will be unable to avoid overshooting the aerodrome. Thus in order to approach the modern aeroplane successfully the throttle has to be closed at some point when the pilot

is certain he has *not yet reached* the basic gliding angle line. That is, he must be sure of undershooting. As the aerodrome approach boundary is neared the extent of the undershooting can be more accurately gauged and reduced by flattening the gliding angle by use of the engines. This is known as the " Undershoot Technique." It will be seen that in the overshoot technique care has to be taken not to come below the basic gliding angle line, whereas in the undershoot technique care has to be taken not to go *above* the basic gliding angle line (to be exact the maximum gliding angle line, but as the two are nearly co-incident on modern types the basic line may conveniently represent the boundary between overshoot and undershoot technique). The final result of modern types is that the overshoot technique has had to be abandoned in favour of the undershoot technique.

The real reason for this is that pilots have found it impossible to touch down within a reasonable distance of a selected point without the ability to vary the gliding angle considerably from the basic gliding angle. In order to achieve sufficient control of the gliding angle the basic angle has to be made the upper limit and level flight *with engine* the lower.

When the flaps produce sufficient drag to make the basic gliding angle steep the power approach is fairly easy because, though flatter than the basic angle, the actual angle of approach can still be fairly steep. Moreover, with a flap which

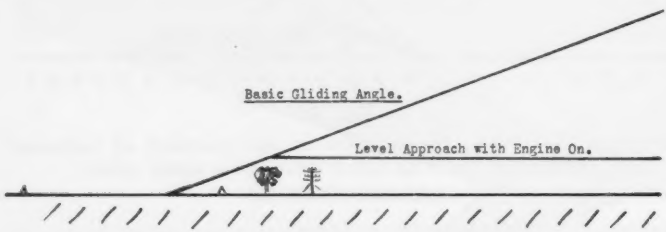


FIG. 10.

Power approach—using undershoot technique.

produces a steep basic angle the deceleration of the aeroplane is fairly rapid, which allows a small speed variation in the glide and a basic gliding speed not too close to the stall.

If, however, the increase of drag associated with the increase of lift as the flaps are lowered is small (as it has to be when the flaps are designed primarily for take-off) the basic gliding angle with flaps down is so flat that the approach, which must be flatter still, becomes extremely difficult. The opinion among the majority of pilots with whom I have discussed this problem is that drag, and plenty of it, is really what is wanted from the landing point of view, and they are prepared to sacrifice quite a lot in the reduction of the stalling speed in order to obtain the increased drag. We may conclude, therefore, that, for the average pilot, the power approach (or the undershoot technique) is a feasible method of approaching and landing provided there is plenty of drag, in order that the aeroplane, having been flown in at a speed well above the stall, decelerates quickly and touches down soon after crossing the aerodrome boundary. " High drag for landing " is the slogan.

What now of the forced landing? When the overshoot technique was possible the chances of making a successful forced landing were reasonable and for every one that failed probably three or four were successful. Possibly they were more frequent than is likely now, but every pilot felt he had a reasonable chance of making a forced landing if the occasion arose. The situation has changed. The mere fact of resorting to the undershoot technique for landing on aerodromes

means that pilots are not practised in approaching without engine, and, moreover, when the occasion does arise the judgment of the approach is far more difficult. It is no good trying to disguise the fact that providence plays the leading role in a forced landing so far as the average pilot is concerned. The best the pilot can do is to leave his undercarriage up and give himself a little latitude in the judgment of the glide by reducing his landing run, owing to the rapid deceleration of the aeroplane landing on the fuselage.

The next point that arises is, of course, the much debated question as to whether in view of the increased reliability of engines, and the fact that in the future most aeroplanes will have not less than two engines, the chance of a forced landing has been reduced so much that it is not worthwhile attempting to find ways and means of improving the chances of forced landing successfully. From the point of view of a pilot my answer is definitely and emphatically that it is worthwhile. But I will qualify that statement by saying that I am not asking, nor do I think it reasonable to ask, for this, if it cannot be provided without a serious loss of performance or load carrying capacity. Incidentally if five in every hundred aeroplanes used to force land, four would probably have been successful. Now perhaps only one in every hundred will force land, but it is bound to be damaged. Thus we are really no better off than before. I feel that perhaps this aspect of the change in design has not been fully appreciated, and that perhaps pilots as a whole have not voiced their difficulties loud enough, or possibly they are reticent to admit defeat. If, after the pilots' difficulties have been fully grasped and a serious investigation has been made to solve them, no solution, which does not seriously detract from other essential qualities in the aeroplane, can be found, pilots will just have to accept the situation. (I think in this event the real power landing with large throttle openings and fully flapped wings with slots and interceptors should be more highly developed.)

I feel, however, that a solution will be found and I will outline one which from my experience seems promising. Let us first be quite clear what we have got to do. The present situation has arisen from two factors:—

(*a*) From the increase in the transition distance.

(*b*) From the very much smaller difference between the basic gliding angle and the maximum gliding angle.

The first, I think, must be accepted as inevitable, since it depends on the basic gliding speed, manœuvreability and the pilot's view. The only factor that might receive attention is the last. For a given size of aeroplane and given basic gliding speed the one that allows the better all round view will have the lower transition point. Good view sideways should, therefore, be aimed at where possible; good view forward is not enough.

The solution to the problem must come from the second factor. The difference between the maximum glide and the basic glide must be greatly increased. This can only be achieved by providing variable drag in large quantities. Two means are available for doing this; firstly, aeroplanes might be designed to be able to sideslip and crab to an extent more nearly comparable with our older type planes. Without fitting enormous rudders this could only be done at the expense of directional stability. For other reasons a high degree of directional stability is desirable, so I do not think that increasing the ability to sideslip will ultimately provide a solution. My last hope and the one in which I pin my faith is the development of a variable air brake.

Let me most emphatically state at the outset, so there can be no misunderstanding, that the variable drag will have to be provided.

(*a*) *Without* changing the stalling speed.

(*b*) *Without* producing a change in trim of the aeroplane greater than is normally associated with variation of throttle setting.

Assuming for a moment that variable drag in large quantities can be provided by an air brake let us be quite clear as to its effect upon the aeroplane.

Referring to Fig. 11, let CAB be the flattest gliding path of the aeroplane. If at A the pilot opens his throttle a little, but wants to maintain the same air speed, his aeroplane will begin to accelerate in the direction AB and, to keep the speed the same, he will have to pull the nose up a little until equilibrium is again restored at the new gliding angle $A_1\ B_1$. Had he opened his throttle a little more he would have followed the curve AA_2 and the new gliding angle would have been $A_2\ B_2$. In other words, opening the throttle merely decreases the gliding angle and closing the throttle increases it. Let us suppose, however, that CA is the best gliding angle of a modern aeroplane with the flaps and undercarriage down. Further let us suppose that at A the pilot raises the undercarriage. By so doing he will have reduced the drag and if he keeps the aeroplane at the same attitude it will begin to accelerate down AB. To keep the speed constant he will have to pull the nose up a little, until eventually the aeroplane will glide at a new angle $A_o\ B_o$. The effect of decreasing the drag has been identical with the effect of opening the throttle a little; in each case the glide has been

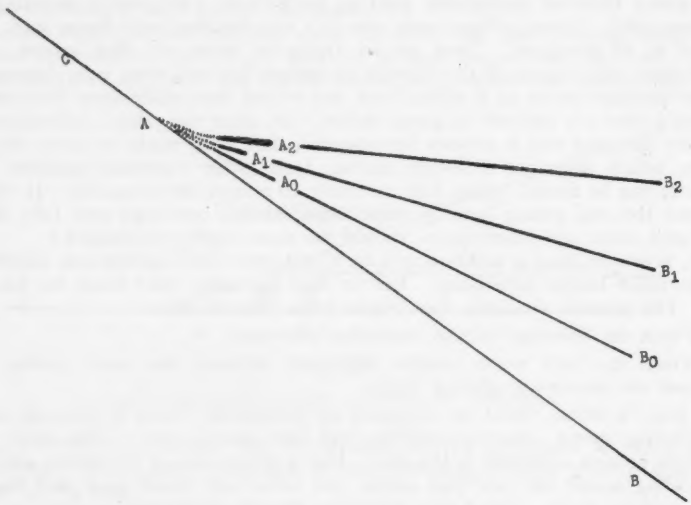


FIG. 11.
Variation of gliding angle.

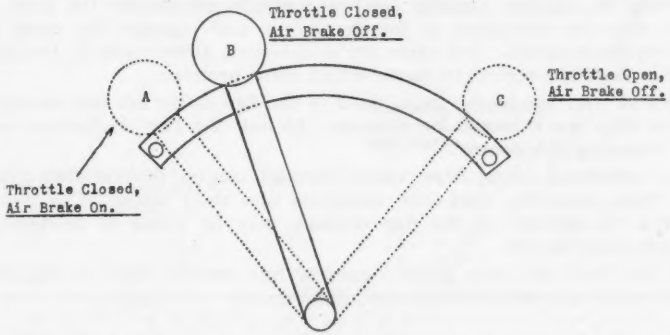
flattened slightly. No one can possibly argue that the reduction of the drag is accompanied by any sinking of the aeroplane; neither can they argue that at one moment you are flying one aeroplane and at the next moment another aeroplane—at least to no greater extent than when the throttle is varied. What I want to make perfectly clear, because there has been so much confused thought on this point, is that variation of drag is identical in its effect with variation of throttle setting. Decreasing the drag corresponds to opening the throttle; increasing the drag corresponds to closing the throttle.

Suppose for the sake of example it is arranged that when the throttle (see Fig. 12) is in position B the engines are ticking over and movement of the throttle from B to A leaves the engines ticking over but operates a valve which lowers the undercarriage. When the pilot reaches A (Fig. 11) all he has to do to flatten the glide is to open his throttle; the first movement of which raises the undercarriage without increasing the engine speed. The first portion of the flattening of the gliding angle will be due to loss of drag, while subsequent

flattening will be due to thrust from the engines. But, if the pilot could not hear his engines nor see his revolution counters, he would not know when the flattening ceased to be due to reduction of drag and began to be obtained by increasing engine revolutions. For all he knew the whole of the flattening might have been due to increased engine revolutions. I am not suggesting that the undercarriage should be raised and lowered to obtain variable drag. I am merely using it as a means of illustrating that drag variation may be treated as variation of engine speed.

Split flaps increase the value of the lift coefficient as they are deflected, up to a deflection of 60° or so. Further deflection does not alter the value of the lift coefficient, but it *does* increase the drag coefficient.

Thus split flaps varied between a deflection of 90° and 60° provide a means of varying the drag without changing the value of lift coefficient, *i.e.*, without changing the stalling speed of the aeroplane. Split flaps hinged about their leading edge required large forces to lower them to 90°. Nevertheless, there are aeroplanes which have large split flaps which do go down to 90° and, even with the engine(s) throttled back, open quickly. They are operated merely by pushing a small button, or moving a small lever. It could be arranged that by pushing



Arrangements made so that moving throttle from B to A will only operate Air Brake if Lift Button has already been set for landing.

FIG. 12.

Air brake connected to throttle.

one button, which I will call the lift button, the flaps would come down to the angle at which C_L maximum is obtained, and by pushing another small button, which I will call the drag button, the flaps are lowered to an angle of 90°. It would not be difficult, then, to arrange for the drag button to be connected to the throttle so that a backward movement of the throttle beyond the conventional closed position caused the flaps to come down from the position of just reaching C_L max. to 90°. If the throttle is moved forward again to the conventional closed position it would operate the drag button so as to raise the flap to the original position. The flap displacement should be proportional to throttle movement, but, if that proved too difficult, a two-position arangement would be very welcome. A pilot preparing to land would press the lift button and by so doing reduce his stalling speed to the minimum possible owing to the flap being lowered to the position where C_L max. is just reached. Having done that he would forget about the lift button for the rest of the landing. He would then manœuvre the aeroplane so that on reaching the approach transition point he felt sure he was above the basic gliding angle line. He would then point the nose of the aeroplane at the approach boundary—no real judgment would be required—and he would keep the speed of the glide at the desired value by using his throttle over its aft

range to control the drag. If the flap were large enough the old overshoot technique could be used again. I am confident from my experience on large and small aeroplanes that this technique is applicable to all aeroplanes regardless of size. After all, the technique is exactly the same as that of the power approach. The throttle is used in both cases to vary the gliding angle, which variation is obtained in one case by varying the thrust and in the other by varying the drag. Incidentally, if the pilot has to go round again for some reason, such as being baulked, he merely opens his throttle fully. Automatically as much drag as possible is lost without losing lift, then at some safe height the pilot can operate the lift button and raise the flaps completely.

Big aeroplanes require large flaps which entail heavy operating forces. But big aeroplanes have large control surfaces, which are none the less operated by the same source of power as the controls of smaller aeroplanes; that is by the human being. This was achieved when the need became pressing by designing partially self-balancing control surfaces. The need has now become manifest for large flaps to be operated by small forces, and so the plain split flap must give way to the balanced flap just as the plain hinged control had to give way to the balanced control. If we cannot get away from the idea of the plain split flap hinged at the leading edge, then, admittedly for large aeroplanes, the problem of providing an efficient variable air brake which will enable the pilot, within limits, to dive the aeroplane at the aerodrome and regulate his speed by the brake is beyond solution. But there are in existence already one or two balanced flaps, while there are several on paper which show promise.

Changes of trim due to the latter third of the flap range are not usually great, and where they are it would be necessary to link the flap mechanism with the elevator trimming tab control.

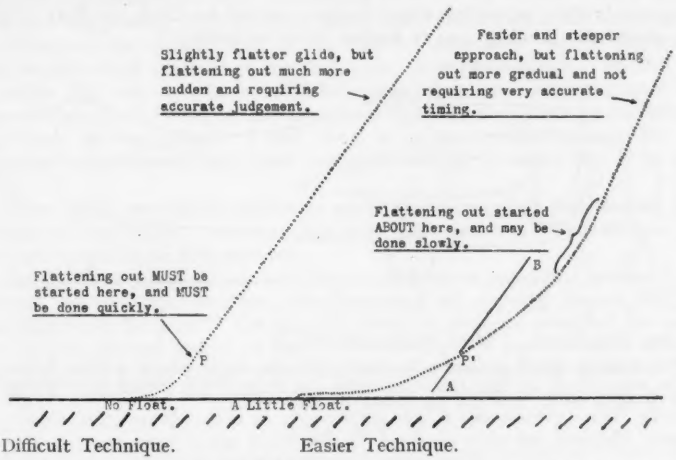
I have considered using flaps varied through angles beyond that giving C_L max. I think, however, that once designers turn their attention to this matter other ways, in addition to the flap method, may be found of producing drag without affecting the lift.

When the need has been great ingenuity has usually risen to the occasion, and I feel it will not fail us in this instance.

Flattening Out.

Whenever there has been mention of high drag objections to it have been raised on the score of the difficulty of flattening out and the high degree of skill demanded. This seems to me to arise from a lack of appreciation of the technique of flattening out with high drag. When the basic gliding angle is flat failure to flatten out at the right moment will not have serious consequences. If left too late the aeroplane will probably bounce, but it will not nose over. If done too early, owing to deceleration being slow, the pilot will become aware of his error in time to use the engine to prevent the aeroplane dropping heavily on to the ground. When the basic gliding angle is steep failure to flatten out at the right moment leads to dangers. If left too late the aeroplane may turn over on to its nose or back. If done too early, owing to the rapid deceleration, the aeroplane stalls and drops heavily on to the ground before the pilot has time to use his engine. Remembering that the basic gliding speed is the speed necessary in the glide for the aeroplane to touch down as soon as flattening out has been completed it is clear that, when the drag is low, the basic gliding speed is near the stalling speed. As the drag increases the basic gliding speed increases owing to the greater angle through which the aeroplane has to be rotated to flatten out, and owing to the more rapid deceleration during that process. When the drag is low we dare not glide more than a few miles per hour faster than the basic gliding speed, owing to the long float that would result. This is really the root of the whole trouble. As the drag increases there seems to be no difficulty in appreciating that the basic gliding speed increases relative to the stalling speed. But

there is a reluctance to increase the actual gliding speed relative to the basic speed. This is, of course, exactly what should be done. The higher drag enables speeds well in excess of the basic speed to be used in the glide without producing excessive float. What should be done and what makes flattening out with high drag quite simple is to glide at a speed well above the basic speed. It is then possible to begin flattening out quite high and bring the aeroplane in a gentle curve down over the aerodrome with still a little speed left to produce a short float, during which the height may be finally adjusted before the stall is reached. In this manner the glide is flattened before the ground is unpleasantly close. There are other incidental advantages from the fast gliding speed, the chief of which is that the speed need not be kept within fine limits owing to its being far removed from the stall. (In passing, another important result is that the aeroplane could not approach the stalling attitude without the pilot being aware that it was departing from the correct gliding attitude.)


Slightly flatter glide, but flattening out much more sudden and requiring accurate judgement.
Faster and steeper approach, but flattening out more gradual and not requiring very accurate timing.
Flattening out started ABOUT here, and may be done slowly.
Flattening out MUST be started here, and MUST be done quickly.
B
P
P'
A
No Float.
A Little Float.
Difficult Technique.
Easier Technique.

P and P′ are at the same height. The line AB represents the angle of the glide at height P when the *no float* landing is aimed at. If a little float is aimed at, though at the start the approach is steeper, flattening out can be started earlier thus avoiding the necessity of maintaining a steep gliding angle close to the ground.

FIG. 13.

Flattening out with high drag.

Flattening out has been considered in relation to the type of landing technique used at present. It will be appreciated later that flattening out will be greatly simplified if the altered landing technique, suggested in what follows, is adopted.

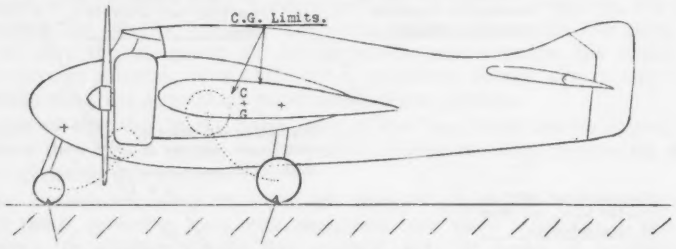
TOUCHING DOWN.

Having crossed the aerodrome boundary the one thing above all others that a pilot wants to do is to touch down and get his aeroplane under control on the ground. What pilot does not know the unpleasant sensation of floating, wasting yards and yards of space, and wondering whether the aeroplane will touch down in time to pull up before the end of the aerodrome? This is the penalty paid for coming in a little too fast. The float is unavoidable because, if any attempt is made to force the aeroplane on to the ground before it reaches its ground angle, contact with the aerodrome surface produces reactions, which throw the aeroplane back into the air, and which are too powerful for the flying controls to overcome.

This arises from the arrangement of the conventional undercarriage.

To prevent reactions at touch-down throwing the aeroplane into the air the aeroplane must not be allowed to touch the ground until it can do so with the tail wheel and main wheels together. Thus, after crossing the aerodrome boundary the pilot has to do the one thing he does not want to do and logically should not be required to do: that is, to keep the aeroplane off the ground until he has been able to lower the tail so that the main wheels and tail wheel touch together. When the pilot is sitting well behind the nose this is comparatively easy, but when he is sitting in the nose so that he cannot see the aeroplane he is flying, it is difficult.

On the older types of aeroplanes a bad landing and bounce did not matter so much, because landing speeds were slower and opening the throttle enabled the aeroplane to be " hauled " into the air and flown round again. On the new types it matters a great deal, landing speeds are higher and the throttle cannot be relied upon to save the situation to the same extent. Another defect of the conventional undercarriage is that powerful wheel brakes cannot be used, so that even after touching down the landing run is longer than necessary.



Castoring Nose Wheel. Main Wheels behind C.G.

The landing would probably be made with the main wheels a little below the nose wheel so that the wing, with the flaps down, would be working at a value of C_L not too far below its maximum.

FIG. 14.

Nose wheel undercarriage.

The nose wheel undercarriage provides a remedy for all these difficulties. Its principal advantages are:—

(*a*) Bouncing is eliminated so a pilot, who has come in too fast, can fly the aeroplane gently on to the ground and put on his brakes.

(*b*) Risk of overturning is practically eliminated and cannot be caused by full application of the brakes.

(*c*) Directional stability on the ground is obtained, allowing fast taxying.

(*d*) Owing to a slight negative angle of incidence a higher coefficient of friction is obtained between the wheels and the ground, which produces more rapid deceleration at the beginning of the landing run.

(*e*) When landing with drift no strain is thrown on the undercarriage as the front wheel castors on touching the ground, and points the aeroplane in the direction in which it is drifting.

(*f*) It aids the take-off because the aircraft is practically in flying position at the start. Moreover, it greatly assists in taking off over rough ground as it prevents the aeroplane being flung into the air before it has reached flying speed. (It is rather difficult to prevent a disconcerting porpoising on some types of aeroplane with the conventional undercarriage at the moment.) One further advantage has been claimed for the take-off and

that is that owing to high directional stability on the ground, the aeroplane can be taxied fast towards the lee boundary and then swung round into the wind with an initial speed of some 15 to 20 m.p.h. at the beginning of the take-off run.

With such an undercarriage the aeroplane is merely flown on to the ground, all the difficult and wasteful holding off is eliminated. Blind landings and night landings become matters of comparative simplicity. Calculations show, so I am told, and my own experience has verified, that if the aeroplane is brought in fast, flown on to the ground and the brakes applied, it will come to rest at a point before that at which it would have touched down had it been held off in the normal manner.

Someone, well-known in the sphere of aviation and who has had considerable experience of nose wheel undercarriages, told me that in practice many incidental advantages were found which had not been thought about in theory, while no unexpected disadvantages were discovered.

I am not suggesting that existing aeroplanes should be fitted with nose wheel undercarriages, for clearly that is impossible; moreover, single engine aircraft do not readily lend themselves to this type of undercarriage. In the future it is probable that no aeroplanes will have less than two engines, and it should not be difficult to fit nose wheel undercarriages as they can be included in the design from the beginning. I feel there is an overwhelming case for adopting the nose wheel undercarriage, and provision should be made for it in all future designs.

We have made enormous strides in many directions, but the landing technique has remained stationary. A stage has now been reached when serious consideration must be given to this problem.

As speeds have gone up on land more and more powerful brakes have been designed. Yet on the aeroplane, the fastest of all moving things, there are no brakes which can be used in the air, and those at present provided for use on the ground are of limited power to avoid overturning. I am confident that landing can be made safer and easier when the problem receives the attention it merits. From my experience I am convinced that one solution at any rate is along the lines I have suggested. Given a powerful air brake and a nose wheel undercarriage I believe that wing loadings at landing may be possible considerably beyond the values now contemplated.

Summary.

Take-off.

From the pilots' point of view increased wing loadings do not present a problem. That has to be solved by designers beforehand. Wing loadings are, however, rapidly approaching a value beyond which I do not believe wing surface devices will provide a solution to the take-off problem without greatly increasing the size of aerodromes and making them invulnerable to weather conditions (a difficult problem in this country and very expensive). The principle of the assisted take-off will soon have to be put to practical use. Once it is adopted the range and load carrying capacity of aeroplanes will increase greatly because, in the first place take-off will be possible at very high wing loadings, and in the second place wing surface devices will be able to be designed entirely to make for ease of landing and allow such aeroplanes, considerably lightened at the end of their journey, to be landed on average size aerodromes.

Irreversible Ailerons.

From the point of view of blind flying alone non-self-centring ailerons are neither dangerous nor impracticable on any type of aeroplane, their effect being to increase the strain slightly on the smaller types, while reducing it on the larger.

From considerations other than blind flying it is desirable—though not essential—to have self-centring aileron controls on aeroplanes carrying fixed front guns. It seems possible that ailerons that are both self-centring and irreversible may be fitted to such aeroplanes.

From this it follows that if no other simple and reliable method of preventing flutter can be found, the method of using irreversible aileron controls offers a practicable solution.

The Approach.

It has become necessary to use the engine during an approach. Provided high drag flaps are employed this method of approach is fairly easy for an average pilot. Successful forced landings are now impossible. Despite the chances of forced landings being less an endeavour should be made to find a means of making it reasonably possible to force land successfully. If no means which does not detract seriously from performance can be found the present situation must be accepted. It seems, however, that a form of balanced flap used beyond the point of reaching C_L maximum provides a means well worth trying out as its success would solve the problem for small and large aeroplanes alike. Given a powerful *air brake* approaching would become merely a matter of doing a gentle dive towards the aerodrome and preventing the speed becoming too high by using the air brake.

Flattening Out.

The objections put forward in some quarters to flattening out with high drag arise from a failure to adopt the correct technique. If sufficient speed is maintained in the glide to enable flattening out to be started high, so the aeroplane can be brought in a gradual sweep to the proximity of the ground with a little subsequent float, flattening out with high drag is really quite easy.

Touching Down.

Much of the difficulty of landing arises from faults inseparable from the conventional undercarriage. These faults introduce real dangers in blind landings and night landings. The nose wheel undercarriage eliminates such faults and makes landing—the approach having been correctly judged—a matter of extreme simplicity. The nose wheel undercarriage should be fitted to all future designs.

Following the paper, two cinematograph films were shown, the first illustrating landings by a " Parasol " monoplane with and without flaps to increase the drag. The horizontal distance of travel between the point at which the machine was at a height of 50 ft. and the point of rest was very much reduced as the result of the use of the Zap flap. When the flap was fully down, there was no float, the machine touching down directly it approached the ground.

The second film illustrated the ease of landing and take-off in a machine fitted with a nose-wheel undercarriage. Squadron Leader Fraser commented that there was no tendency to " shouldering " in a machine with a nose-wheel undercarriage, and it was delightful not to have to fiddle with the stick when landing in order to prevent nosing or to bring the machine back to the ground.

Discussion.

The Chairman: The more one considered the latest developments in aircraft the more one appreciated that the men who had made aeroplanes before the war had made them right. The latest tricycle undercarriage reminded him of some of the early machines of Breguet, and some of the early Bristol machines, each of which had a wheel in front in order to prevent them nosing over. They seemed now to have reached the second childhood of aeroplanes, in which they were reverting to the things they had used in the early days.

Mr. P. W. S. BULMAN (*Fellow*): He felt as though he was being asked to open the prosecution; and it was particularly hard to have to shoot at his good friend, Squadron Leader Fraser. Pilots were notorious in that they usually found it difficult to agree, and he felt that their dirty linen should be washed in private rather than in public!

His own opinion was that the take-off was the problem of the future and that this would tend towards concentration on variable area and high lift devices. The author had rendered valuable service in this paper by pointing out that such devices must be considered with reference to the landing problem when what the pilot wanted was drag, and as much of it as he could get. He confessed that when he had read the paper, he had felt that the author had considered the whole technique of landing from the point of view of the old-fashioned technique of landing without engine, and of forced landing; possibly the author had been influenced by the necessity for doing so many tests at Farnborough in which the engine-off landing was necessary. His own impression was that in future the take-off would be the serious problem, not from the point of view of the pilot, but of the designer. The take-off appeared to him to be limited, not by the run available, which need not be excessive if runways were contemplated, so much as by the necessity for a reasonably good initial rate of climb. The author had not made any mention of ground effect, and it might well be that, either with assisted take-offs or with take-offs on prepared runways, the rate of climb after leaving the region in which the ground effect was present would be nil.

With regard to irreversible aileron control, he believed he would have some backing if he referred to the device shown in Fig. 1 (showing the principle by which irreversibility could be obtained in a flying control) as "that terrible rat-trap." If a constructor had put such a suggestion to the Air Ministry he would have been thrown into a deep dungeon and kept there for the satisfaction of D.T.D.! Who would like to fly an aeroplane having a piece of mechanism with such possibilities of jambing the control?

But apart from that, the author himself had put forward several objections to irreversible control. One of the great problems had been to obtain accurate self-centring. Mr. Bulman referred to the motor car for purposes of comparison, for the control and stability of the motor car presented many points in common with those of the aeroplane. He could imagine some form of steering gearbox on the hinge of each aileron which would secure the irreversibility which was required from the wing aileron flutter point of view, and at the same time retain a degree of self-centring which was obviously desirable. He suggested that if the millions of motor cars which had been produced could have been rendered free from all trace of wheel wobble and front-end shake by such simple means, the enormous sums of money which the motor car manufacturers had devoted to research must have been wasted. It was not without significance that the motoring public continued to demand self-centring steering.

Another point to be borne in mind in connection with irreversible control was that, in wartime, any damage to the circuit would leave the pilot of a machine in a very difficult position unless, at the moment the damage was caused to the circuit, the ailerons happened to be in the neutral position or complete independence of each aileron control circuit were provided.

With regard to the problems of landing, the author had made very heavy weather indeed. From the very excellent film that had been shown of the fully flapped landing of the "Parasol" machine and from a paragraph in the paper one gathered that what was wanted was drag, that one could not have too much drag, and that the best and simplest means of controlling the drag was with the throttle. This has the advantage of being partly instinctive or at any rate easily learnt; in fact the undershooting type of landing was in common use already. The complication of the variable drag flap to the mechanism of the

aircraft and the additional training time required to master the forced landing technique with a further combination of controls must not be overlooked.

A further advantage was the well known addition to lift from the slipstream, and another point of equal importance was the stabilising effect of the slipstream on the controls and the prevention of breakaway of the flow from the wing as the stall approached. It was a most valuable feature, and the degree of safety which was obtained in the vicinity of the stall by retaining the power until the last moment of landing, was too great to throw away with equanimity.

He had flown one of the earlier machines fitted with a four-wheel undercarriage with the main wheels only slightly aft of the centre of gravity. Such an aircraft could be landed in any attitude, there being a reduced pitching moment about the centre of gravity and less tendency to bounce. A tail wheel for emergency use would render such an aircraft almost foolproof on the ground.

One of the most important points in connection with the three-wheel undercarriage appeared to be the possibility of limiting the up elevator control. He would like the author's views on that point, because in normal flight there was no necessity to use 80 per cent. of the up elevator control provided on most modern aircraft except for landing C.G. forward. Should that be the case, he saw no reason whatever why the aircraft should not be so designed with the centre of gravity so far forward that it could not approach the stall with the engine off. The author had shown that there was no need nowadays for the big wing incidence which was necessary in the past to provide drag after the aircraft had touched the ground; with that drag replaced by wheel brakes and by such an arrangement, a great step forward towards the safe aeroplane was within their grasp.

In conclusion, he said the author had been very sporting in putting such controversial matters on paper and so laying himself open to be shot at, not only by pilots, but also by the experts; one envied him his courage, and congratulated him on such a stimulating lecture.

Captain FRANK COURTNEY: He had had experience of flying aircraft fitted with three-wheel undercarriages. The points raised in the paper had more importance than might be appreciated, because the history of aviation, from the point of view of the pilot, had been roughly that his aeroplanes had become more and more dangerous by the provisions made for higher speeds and higher loadings, and he had been asked to get by with it as best he could. When the point was reached at which he could not get by with it any longer, new safety devices were introduced so that, instead of bringing the aeroplane to rest at a distance of only about 5 ft. from the far end of the aerodrome, he was able to bring it to rest at a distance of 50 ft. from the far end. Then more load was added, again the pilot could bring the aeroplane to rest only at about 5 ft. from the far end of the aerodrome, but within a few years he was able to bring it to rest with a margin of 50 ft. Then the experts decided that they must provide more speed, and so the wings were cut down. That process had been going on ever since aeroplanes were first used, and rapidity of development was such that, although a regular and highly skilled pilot could land the machines satisfactorily, difficulties would arise under wartime conditions. It must be borne in mind that in wartime they would not be able to train pilots as they were trained in peacetime. When the highly skilled pilots had been used up they would again be in the position which had obtained during the last war, and pilots would be whizzed through their training with only a few hours of flying instruction, trusting far more to providence than training. He was afraid that unless something were done to increase the safety of putting aeroplanes down, they would use them up at an extremely rapid rate.

In adopting the tricycle landing gear they were harking back to the old days, as the Chairman had indicated. But it had suddenly been surrounded by an air of mystery, as something which was very new and which needed serious thought before they did anything with it; there appeared also to be a wonderful

technique connected with it, though he did not know what it was, and altogether it seemed to be regarded as something altogether mysterious. He drew attention, therefore, to an amphibian which he had built, four or five years ago, for the Curtiss-Wright Company, and to which a three-wheel landing gear was fitted. He had not fitted the nose wheel just because he had thought that it would be a good thing to have; it had been incorporated in the course of ordinary design. When he had tried it out he had experienced no trouble of any kind, and indeed, it had given rather better results than he had expected. Its adoption had become necessary because he had had some rather tough specifications to fulfil. He had had to design the machine as a biplane because of limited span, and he could not use flaps on a biplane because of ensuring water clearance, so that he had to adopt other means of bringing the machine to rest in the specified distance. Therefore, he had placed the main wheels farther back and had included the nose wheel. He had found that by placing the main wheels farther back he was able to get them into the hull without interfering with the passenger accommodation. In the course of about 200 hours flying—of which he had done about half—all kinds of landings were made at various places between St. Louis and New York, and it had worked very well. He suggested, therefore, that British designers were inclined to be too timid in attacking such problems.

Illustrating the machine by means of photographs, Captain Courtney said that the nose wheel was cantilevered, and rather heavier loads were imposed on it when landing than one would expect in modern aircraft, owing to the very high thrust line and the high centre of gravity. But there was no trouble with it. The nose wheel was given an exceptionally long shock-absorbing travel—an important matter, bearing in mind Squadron Leader Fraser's remarks on porpoising.

The water rudders deserved comment because he had fitted them on a spring. He had considered that the machine would land at the maximum angle, in the ordinary way, and therefore, the water rudders would act as a light tail skid. Inasmuch as the machine was amphibian, he had had to make all the arrangements water-tight, and he had tackled the problem in what appeared to be the most difficult way; yet there was no particular difficulty about it.

Illustrating the nose wheel retraction system, he said he had had to provide a water-tight box, and had had a cantilever shaft which went up into the box. It was a very good arrangement, but it was not beautiful, and in the second machine he had had a link gear which went into the box.

Mr. W. O. MANNING: Was the nose ring castored?

Captain COURTNEY: Yes. The great advantage of the tricycle landing gear was not so much that it enabled the pilot to fly into the ground, because obviously if that were done the machine was not landing at the maximum angle; it gave a vertical rate of descent greater than the normal, and therefore, a bigger load was imposed on the landing gear. But he could, if necessary, land the machine at that attitude; when he had become accustomed to it he had landed with the brakes on, and nothing exciting had happened. The water rudders barely touched the ground, and as soon as the machine landed it went forward on to the nose wheel. It had been commented from time to time that that type of landing would tend to throw the passengers forward. But in the amphibian he had designed, the effect of landing was exactly the same as that of coming down on water; when the main wheels touched the ground, the machine went forward gradually on to the nose wheel. Incidentally, there was a perfectly good forward view.

The castoring of the nose wheel, referred to by Mr. Manning, was an important feature, because although it had been suggested that the use of the tricycle landing gear involved the risk of turning over on one of the front legs of the triangle, it was in fact almost impossible to turn the machine over when the nose wheel was castored. Discussing the reason for that, he said that if the left wheel were braked and the right wheel were not braked when the machine

touched the ground it would tend to swing to the left, and therefore, the tendency would be to turn over on the right forward leg of the triangle. But when it tried to do that, the nose wheel would swivel, the left wheel would come off the ground and the machine would swing to the right. If the right wheel were jammed, the machine would continue to be corrected by the swivelling until it came to rest.

Mr. HOLLIS WILLIAMS (*Fellow*): He was not sure that the importance of the tricycle chassis development was fully appreciated, and he expressed the opinion that this simple development, which had appeared on some of the earliest machines was now, at its re-introduction, the most important milestone that had happened in connection with aviation for many years.

He reviewed the many improvements which have been made including aerodynamic refinements, mechanical complexities, development of instrument and radio equipment and de-icing gear, and it seems that all these have made it possible for pilots to fly aircraft which would otherwise be unhandable, or under conditions which would otherwise be impossible.

During the period of intensive development which has gone on for the last decade, and particularly during the last few years, there has, however, been no development which has reduced the skill required for landing until the tricycle chassis was introduced.

The ability to leave and make contact with the ground safely required practically the whole of the time spent in a pilot's early training, and the reduction in the standard of skill required for this manœuvre is so great with the tricycle chassis, that practically the whole of this training period is cut out, and he thought that the country which first produced machines fitted with the tricycle chassis would have a tremendous advantage in emergency by reason of the increase in available man power, and the reduction in wastage of material and, in consequence, would gain tremendously in air power.

The adoption of the tricycle chassis by air transport organisations would result in reducing materially the strain on the pilots, and it would confer other advantages which increased the margin of safety. Again, from the point of view of the man in the street, it brought air motoring many stages nearer.

Discussing some of the features of the tricycle chassis which appealed to the pilot, he urged that the method of taking-off a machine fitted with the conventional type of chassis was completely wrong. The pilot taxied the machine to a suitable point on the aerodrome, brought it to rest, turned, started and accelerated in order to attain a certain speed within the shortest possible distance, and so ensured a sufficient margin for the take-off. To illustrate the advantage of using the tricycle chassis, with which the machine could be swung round without having to stop, he mentioned the parallel case of a motor car on a vast expanse of concrete. If the driver of a car wished to attain a certain speed within a certain distance from the edge of the expanse of concrete, he would not drive to the edge, stop the car, turn it, and then start from a standstill; he would drive round the boundary, accelerating all the way, and swing into the starting stretch at a high speed. This cannot be done on an aeroplane with the normal chassis, because of its directional instability. An aeroplane with a tricycle chassis, however, was divorced from the disadvantages of instability of direction, etc; and the pilot felt that he could handle the aeroplane in the same way as a car. The natural tendency of the pilot in a machine with the tricycle chassis was to taxi fast round the edge of the aerodrome, to swing round into wind and take-off, in the manner shown clearly in the cinematograph film with which the paper had been illustrated, and thus it gives the advantage of a simple form of accelerated take-off. From his experience he claimed that it was all advantage and that there were no disadvantages.

Discussing the landing problem, he illustrated it by means of a diagram plotting contact speed against vertical velocity.

The curve shown was self-explanatory, and showed that with the normal chassis the pilot has to skilfully select conditions within narrow limitations in order to make a safe landing, whereas with the tricycle chassis he has a wide range of variation in speed and vertical velocity from which to choose.

The relative sizes of the enclosed areas shown on the diagram are an indication of the relative standards of skill and judgment required, and it can be understood from this that the tolerance in the case of the tricycle chassis is so great that anyone who can drive a car can land such an aircraft.

To demonstrate the advantages of the tricycle chassis he had taken passengers into the air, had put the machine into a perfectly straight glide towards the ground, had flattened out slightly when near the ground, and had then taken hands and feet off the controls—a perfect landing resulting. The smothered ejaculations and the muscular contractions of his passengers had indicated that that was an effective demonstration.

Another practice was to put the machine into a slow glide, at a controlled rate of descent, and to put it straight to the ground without touching the controls, using only the throttles. That was essentially the fog landing.

Therefore, he supported whole-heartedly the author's recommendation that the tricycle type of chassis should be fitted to all new machines. He was quite sure that machines which had not that type of chassis were coming rapidly to the shadow of obsolescence—and that applied to practically every machine in this country to-day!

Mr. H. F. Vessey (*Associate Fellow*): He regarded the problem of landing with the three-wheel undercarriage from a point of view which was rather different from that of other speakers. The ease with which a machine fitted with that undercarriage could be landed was a very good point. What would normally be grossly bad landings were quite safe with the nose wheel type of undercarriage; one could land the machine without danger at anything from a crash landing at stalling speed to a very high speed landing in which the machine was flown straight on to the ground. But that did not appear to help in the direction of allowing higher wing loadings. In order to allow of higher wing loading, the gliding speed must be fairly slow, so that the machine could be put on to the ground quickly, the brakes applied, and the machine could be brought to rest with a much shorter run than usual. In order to achieve the shortest run it seemed necessary to land at, say, 5 per cent. above the stall; there would be a short flattening out period, so that the vertical velocity would be reduced, followed by a short run. He asked for Squadron Leader Fraser's opinion particularly with regard to gliding in at 5 per cent. above the stall. Presumably he would not like to glide in at that speed; but it was necessary to keep the speed low if wing loadings were to be increased very much.

He suggested that Squadron Leader Fraser was rather pessimistic in stressing the desirability of assisted take-off. Present designs had not very great difficulty in taking off, and he felt that something could be sacrificed by way of take-off in order to secure better landing. As wing loadings increased, the main difficulty would be in connection with landing, rather than take-off; variable pitch airscrews and flaps could be used to assist take-off, and such aids put back the value of assisted take-off as ordinarily understood. No doubt we should have to come to that sooner or later, but he believed it had been postponed for some time to come.

Commenting upon the very good point made by the author, with regard to forced landings, that the undercarriage should be kept up, Mr. Vessey pointed out that that would flatten the gliding angle considerably, and that pilots would get into difficulties if they did not recognise that fact when making forced landings. He suggested that it might be advantageous to put the undercarriage down when gliding, and then to retract it again just before touching down.

Prof. G. T. R. Hill (*Fellow*): He recalled a paper dealing with the manœuvres of taking off and landing, presented to the Society in 1921 by his

brother, who had laid particular emphasis on that occasion on the process of actually touching down; the approach was considered as something which could be effected with ease, whereas real skill was required in making contact with the ground without causing the undercarriage to collapse. In the present paper by Squadron Leader Fraser, greater stress was laid on the approach, and relatively little on the actual contact; and a paper by MacMillan, in 1930, could be regarded as standing in an intermediate position. It seemed that the approach problems, difficult as they were already, would become more difficult, relative to the actual touching down problems.

It had been said that landing was the pilot's greatest problem, and that it could not be assisted. But in his brother's paper of 1921 there was a picture of a device, which could properly be described as a device for assisting landing, constructed to designs by Flight Lieutenant Noakes. A long stick, somewhat resembling that used now for picking up messages was hinged to the front axle, and connected to the joystick; the pilot approached with his hands off the stick, the ground knocked the landing stick which pulled back the joystick, so that the aeroplane sat down perfectly without a jar. The elongated tail skid devised by Flight Lieutenant Palethorpe, which in its effect forestalled the three-wheel undercarriage, for it enabled a machine to be landed without any bounce, was also described in that paper. The machines were biplanes in those days.

Another example of the use of the three-wheeled undercarriage in the past was on the tail first Focke-Wulf, which was demonstrated at Hanworth, some years ago.

The split balanced flap used as a brake, was demonstrated by Squadron Leader Bonham Carter at the Royal Air Force display in 1928, on one of the Pterodactyls which Prof. Hill had built.

With regard to nomenclature, he was not sure that the term " transition point " was very suitably chosen. He suggested as an alternative the term " steadying point," for it indicated the point at which the machine was steadied for the approach. Again, he did not feel happy about the expression " transition error." A pilot might not arrive exactly at the " transition " or " steadying " point, but it was a little hard to call it an " error " if the pilot could still arrive at the desired point on the aerodrome without coming to grief. A word such as " latitude," " allowance " or " tolerance," might be used instead of the word " error."

Finally, Professor Hill took the opportunity to acknowledge how much Squadron Leader Fraser's advice was valued at meetings of the Stability and Control Sub-Committee of the A.R.C.

Squadron Leader J. F. X. McKenna: He was not sure that the author was right in stating that the whole of the take-off problem had really been solved by the designer beforehand or the aeroplane would not be flying. When an aeroplane was in flight, an observer on the ground might be satisfied that the take-off problem had been solved; but sometimes, if he could see the exhausted condition of the gentleman in the cockpit after having got the machine into the air, it would not be so obvious that the take-off problem had been solved.

He did not claim special knowledge concerning the use of flaps to assist take-off, but he said that such flaps did not appear to make much difference to the machines of which he had experience. The manufacturers' pilots who delivered such machines would say that they used a little flap to assist take-off, and the pilots who flew the machines subsequently found that the machines did take off with the aid of the flaps; but sometimes they would forget the flaps, and the machines would still take off, there being little apparent difference whether or not the flaps were used.

As to the suggestion that landing could not be assisted, he said he had always dreamed of assisting the landing by means of the variable pitch airscrew, by adjusting the pitch to give reverse thrust. There might be something in

that. But if that practice were adopted, then once a pilot had decided to land, the die was cast! It might be possible to do something in that direction in the future.

Discussing forced landings, he said he appreciated that the gliding angle was rather flat when the undercarriage was retracted; but he was rather appalled by Mr. Vessey's suggestion to put the wheels down when gliding and then to pull them up again at the last minute, because they could not be pulled up very quickly, especially with emergency hand gear after engine failure and if one wanted to land over a clump of trees, one might be horribly caught out, because the wheels were only half way up. He personally would not recommend it.

It seemed to him that if one landed a machine by what might be called the tricycle technique, it would touch the ground at a greater speed than if it could be held off until stalling incidence be reached, although the effect on the landing run of the greater speed might be offset by more rapid braking.

As to a suggestion that it would be a good thing to reduce the elevator size to reduce the danger when stalled, he said that even if elevator movement be restricted to the greatest practicable extent, it would still be possible to put the aircraft into a stalled position by pulling it up as in the commencement of a loop. This might be done inadvertently, consequent upon partial loss of control in a cloud, and a spin might then result. He did not think the reduction of the elevator size or movement would provide the answer. It was still necessary to make aeroplanes reasonably safe when stalled.

Flight Lieutenant C. S. STANILAND: He had flown only one machine with irreversible ailerons and was not very much impressed by it because self-centring was a most necessary feature. He felt that irreversibility as such should be adopted, but perhaps it would be better done by a self-energising damper; in other words, control would not be affected, but any backlash or flutter would be stopped. He recalled that Flight Lieutenant Bulman had referred to the motor car when discussing irreversible ailerons, and said that quite a lot of motor cars had a self-energising damper on the steering, so that if the front wheels were hit hard the steering did not move at all. In other words, it was a very good anti-flutter device.

Recently he had flown a machine fitted with the tricycle undercarriage, and had landed it with his hands off. It certainly did everything claimed for it by Mr. Hollis Williams. But he urged that it was most important to fit a tail skid. The machine he had flown was fitted with twin rudders, which were below the tailplane, and unfortunately he was not aware that it had not a tail skid. Therefore, when he had tried to make a three-point landing, Mr. Hollis Williams had become worried about the twin rudders. The main reason why a tail skid should be fitted was that in order to land with as short a run as possible, the machine must be brought in reasonably slowly and must touch down at the slowest speed; if it were brought in at the normal flight attitude, and therefore at the normal rather high speed, however good the brakes might be, and especially on wet aerodromes, the machine could not be stopped more quickly with a tricycle undercarriage than with the conventional undercarriage, unless it was landed with the tail down. He could see no reason against landing with the tail down, certainly in the case of military aircraft. Passengers in civil aircraft might object to being thrown forward when landing, however; if such a landing were made when there were coffee cups on the tables, it might be rather disastrous.

Squadron Leader BLUCKE: He urged that the tricycle undercarriage had demonstrated its usefulness particularly for landing an aeroplane in conditions of low visibility. A machine could be brought down to 30 ft. by instruments, and provided the pilot maintained a constant air speed, and rate of descent, there was nothing further for him to do. He agreed with Mr. Hollis Williams that the technique of landing on the throttle was perfectly simple, and he felt that when using the tricycle undercarriage there was no landing problem at all.

Flight Lieutenant QUILL: Many people seemed to think that the three-wheel undercarriage had solved all landing problems, and that machines fitted with it could be landed at almost any speed and would come to rest with a shrieking of brakes within a few yards of touching down. He suggested, however, that particularly on large modern aeroplanes, which occasionally had to land very heavily loaded, even when landing at the lowest possible speed, the brakes, which were working only on two wheels, were already very much over-taxed. It would be difficult to design brakes which would not overheat very much in stopping a machine such as the D.C.4, if the pilot tried to land at fairly high speed with practically a full load of petrol and passengers in emergency, or even if he tried to make an ordinary landing with a full load of passengers. The brakes would constitute a very serious limiting factor to the stopping of a machine which was landed at high speeds. He considered that the proper way in which to land a machine with a three-wheel chassis was always to make contact with the ground at the lowest possible speed; then the pilot could allow the machine to throw forward on to the front wheel after touching down.

The author's suggestion to use the variable air brake connected to the throttle was possibly a little unwise, because unless the mechanical arrangement was so good that there was no difference in the feel of the throttle when pushing the lever forward to release the air brake, and pushing it forward in actually opening the throttle, there was apt to be a rather unequal and uneven movement which might result in choking the engine when trying to open the throttle, due to a sudden reduction in load on the lever. It might be better to have some sort of finger control on the stick for operating the air brake.

Mr. F. RADCLIFFE (*Associate Fellow*): He emphasised that with the use of the three-wheel undercarriage there would be a tendency to land at higher speeds than with the normal or conventional undercarriage. The three-wheel undercarriage had become popular in America of late; but they must not lose sight of the fact that many of the American aerodromes were equipped with concrete runways, and it would appear that the drag that could be obtained with the wheels likely to be used on aeroplanes had reached the maximum to-day. Thus, the length of run before a machine could be brought to the standstill was likely to be very much greater in the future than they had been accustomed to so far, and if they did not increase the number of concrete runways in this country they were likely to be in difficulties in the very near future, when the use of tricycle undercarriages became general.

In a paper given before the S.A.E. of America a year ago, it was stated by a representative of the Boeing Company, that, with the bigger types of aeroplanes it is becoming increasingly more difficult to get adequate braking effect—using normal undercarriages. This was experienced, for example, on the Boeing 299 bomber, for when the pilot applied the brakes often nothing would appear to happen as the machine just slid along the ground and kept on going. It was suggested, therefore, that dual wheels might be essential—all equipped with brakes. If this was the case, therefore, with a normal undercarriage, the tricycle type, with its definite tendency for using higher landing speeds, would seem to indicate that for big aircraft, the braking problem will become of prime importance, and the use of dual side by side wheels very desirable.

Flight Lieutenant BURKE: In supporting the author's remarks with regard to the variable high drag flap, he compared the aeroplane to the motor car. Assuming that he was driving a car without any brakes at all and without a reverse gear, and he wanted to stop the car opposite his front door, he would probably miss it. If he de-clutched some distance away and rolled along the road, he would probably over-shoot the front door and would have to go round a block of houses and try again. That was exactly the problem of bringing an aeroplane having a very flat gliding angle into an aerodrome; if the pilot over-shot, he would fly round and try again. If he fitted a motor car with comparatively inefficient brakes, compared with modern standards, which brakes

required a long time to wind on and wind off, the motor car was comparable with an aeroplane fitted with the commonest form of drag flaps now used; once those flaps were down, the pilot was committed to their use for the rest of the landing. In order to bring an inefficiently braked car to a standstill at his front door, he would first apply the brake, drive the car against the engine until near the door, then de-clutch and the brake would help to stop the car. But car owners would not regard that as satisfactory and would scream to the car manufacturers for something better; they would call for brakes such as were fitted to-day, where the pressure could be varied at will. The aeroplane also could be so fitted, so that the engine could be shut off long before it reached the point it wanted to reach, and the approach could be adjusted by the brake. He had flown only one type of aeroplane fitted with rapidly variable drag flaps; with that machine he could shut off the engine at any height, point the nose straight to the aerodrome, and could guarantee to land within a very few yards of a given point every time without "rumbling," side-slipping, or any other tricks. Such braking had even more advantages on an aeroplane than on a car, because the pilot need not then fly over the house tops when entering an aerodrome such as Farnborough at 5 per cent. above the stall, which would horrify him. When a pilot was flying an aeroplane at a distance of 10 or 12 ft. above the house tops, and at 5 per cent. above the stall, the houses looked very unfriendly, and the slightest error of judgment might mean a close introduction to those houses! Therefore, the variable drag flap was very important, though it had received very little attention during the discussion.

Commenting on Flight Lieutenant Bulman's reference to the advantages of using the engines when landing, and the implication that in these modern days they should rather disregard forced landings, he said that perhaps Flight Lieutenant Bulman flew aeroplanes fitted with new engines received direct from the manufacturers. There were others, however, who had to fly those machines afterwards; they appreciated that engines gradually deteriorated and they liked to consider that they had a reasonable chance of effecting a forced landing if necessary. Perhaps he was unfortunate, for he had until recently averaged one forced landing in every 200 hours flying since he had been in the Service.

Reply to the Discussion.

He quite agreed with Flight Lieutenant Bulman that the take-off would be the problem of the future, not from the point of view of the pilot, but of the designer. Until assisted take-off had been developed there was no doubt that variable area wings and high lift devices would have to fill the gap. He felt, however, that even with such devices there was a limit to the wing loading that could be used. This limit was probably below the wing loading that would be forced upon us if we were to keep ahead of the field in regard to load carrying capacity and range. It would seem, therefore, that the most profitable line to take would be to make every endeavour to develop assisted take-off until it became practicable for everyday use. Having then got the aeroplane with really high wing loading into the air by an assisted take-off, one was freer to concentrate upon designing devices to assist in landing, so that no great increase in skill would be necessary. He agreed with Flight Lieutenant Bulman, as his paper had shown, that the primary requirement for landing was high drag and plenty of it. He had not, as Flight Lieutenant Bulman suggested, considered the whole landing problem from the point of view of the forced landing, for he had said in the paper that "for the average pilot, the power approach is a feasible method of approaching and landing provided there is plenty of drag." He did, however, consider that the forced landing, which, in wartime particularly, may occur for reasons other than pure mechanical failure of the engine, had been completely ignored; increased engine reliability and never less than two engines per aircraft being held to justify such a course. Squadron Leader Fraser felt

that, as much as he would like to take this least line of resistance, he could not accept the contention that the forced landing problem is a thing of the past; at any rate as far as wartime flying was concerned. For this reason he was strongly of the opinion the problem should receive serious attention to see if, after all, it would not be possible to find ways and means of giving control over gliding speeds and angles (besides by using the engine), which would not entail any serious sacrifice in performance and load carrying capacity. The problem was not receiving the attention it merits. If, after being carefully examined by experts, no solution is found, then we shall have tried and failed. At the present time we have failed because we have tried to delude ourselves that there is no problem.

With regard to Flight Lieutenant Bulman's remarks about ground effect, Squadron Leader Fraser said he had not mentioned it because it was a designer's, and not a pilot's, problem. Clearly a satisfactory initial rate of climb must be available after assisted take-off, and designers would have to provide it.

With reference to irreversible aileron control he assured Flight Lieutenant Bulman that the mechanism shown in Fig. 1, which had been referred to as a rat-trap, was only meant to indicate the principle by which irreversibility could be obtained. He had purposely drawn it unlike any actual mechanism that might be designed in order to avoid revealing the details of mechanisms he had actually seen. Such a mechanism was never intended to go into an aeroplane. The actual mechanism would probably be hydraulic, several of which he had seen.

In connection with irreversibility itself, he agreed that one of the great problems in aileron design had been to obtain accurate self-centring, but that was because self-centring ailerons, which do not self-centre if left alone, produce rates of roll, and, if held central to stop the roll, fatigue the pilot. It was probably for this very reason that designers would welcome an irreversible link. Since it seemed possible that self-centring irreversible aileron controls could be fitted if required, it seemed only fair that pilots should allow designers to fit such controls, if by so doing design problems were lessened.

With regard to the reference to the motor car for purposes of comparison, the two problems were not, he thought, analogous, since the motor car depended upon self-centring steering for inherent directional stability, whereas the aeroplane could, if sufficient dihedral was provided, be inherently stable laterally with or without a self-centring control. Squadron Leader Fraser again emphasised that on some aeroplanes irreversible aileron control would be a benefit to the pilot.

With regard to the suggestion that such a device would become very dangerous if the control circuit were shot through in wartime, he said he had seen two or three hydraulic mechanisms and it was a very simple matter to cut out the irreversibility device altogether, leaving exactly the same circuit as would exist if the device had not been fitted, so that the pilot would be no worse off and no better off than with a direct self-centring control.

Commenting on the reference to his having made heavy weather of the landing problem the author was glad to note that he and Flight Lieutenant Bulman seemed to be in agreement regarding the normal landing; both contending that plenty of drag and the throttle should be used. The heavy weather must, therefore, apply to the forced landing. Perhaps he had made heavy weather of it, but others had completely ignored the problem. Though naturally he could not express an authoritative opinion he was by no means convinced that a variable drag mechanism would ultimately entail unacceptable complication; moreover, if the variable drag were operated by the throttle no additional training to teach the forced landing technique would be necessary: The technique used for ordinary landing would cover the forced landing, and would only differ from power approach in that the approach could confidently be made above, instead of below, the basic gliding angle line. Incidentally drag was useful, he said, during the approach, but makes flattening out more difficult, hence variable drag enabled a

steep accurate approach to be made, while avoiding any difficulties during flattening out.

Commenting on the reference to taking advantage of the slipstream from the airscrew when landing, he agreed that if we could not have variable drag, and decided that the engines were always going to be available for landing, we should use a wing combination, which was fully slotted and fully flapped, and should make very much more use of the engines than was the practice at the moment. Nevertheless it seemed to him a poor aeroplane if it needed slipstream over the tail control surfaces in order to flatten out successfully.

Regarding the restriction of the upward movement of the elevator he attached great importance to this point. In fact, he considered that with modern types it would be much more profitable to design the aeroplane so that the maximum incidence that could be reached without a dynamic effect would be below the stalling incidence, than to go to great lengths to provide a dead level stall, possibly at the expense of using structually uneconomic wing plan forms. He had experience of several aeroplanes in which, in fact, this characteristic was present and was quite satisfied that, though it did not prevent the dynamic stall, it allowed the aeroplane to do all it was supposed to do, and did greatly reduce the possibility of an inadvertent stall during an approach to land, or when flying slowly. This feature should definitely receive attention, and he agreed with Flight Lieutenant Bulman that this, combined with powerful wheel brakes to make up for loss of incidence on the ground, put a big step forward towards the safe aeroplane within our grasp.

From his point of view it was refreshing to hear Captain Frank Courtney's remarks, and he was very glad to note in them an appeal to reduce, or at any rate avoid increasing, the standard of skill required of the pilot. With Captain Courtney he felt that if the experts thought only of providing more speed, we may find ourselves in wartime with many very fast aeroplanes, but with comparatively few pilots who could fly them without a period of training that was out of the question in wartime. As in all matters aeronautical, so in this there had to be a compromise. In order, however, to avoid imposing too low a limit of performance it was urgently necessary to simplify the judgment of the approach so that it would be comparatively easy to make use of at least 85 per cent. of the available landing space, and moreover to be able to do so the first time. This, in his opinion demanded, in addition to the throttle to counteract undershooting, some reserve of drag to counteract overshooting. Having arrived accurately over the touch point it was, as Captain Courtney pointed out, only a matter of common sense to fit a landing chassis which firstly did not throw the aeroplane into the air as soon as it touched the ground, secondly produced directional stability and thirdly allowed full application of the brakes without risk of nosing over.

He was glad that Captain Courtney had dealt with the question of the castoring nose wheel and explained how it prevented " shouldering " over. Incidentally, he said, his remarks on porpoising, in the paper, referred to the conventional, and not the nose wheel undercarriage as evidently Captain Courtney had understood him to mean. It was satisfactory to note that the Curtiss-Wright amphibian could be landed at a reasonably high incidence. This dispelled the idea that was prevalent in many quarters, that fitting a nose wheel undercarriage necessarily meant that the aeroplane would have to touch down at some speed well above the stall. There was no more reason for this than simply because a motor car had powerful brakes it should be brought to a screaming stop every time it was necessary to pull up; only in an emergency was that necessary, and so it was with the nose wheel undercarriage.

Squadron Leader Fraser said that as he and Mr. Hollis Williams saw eye to eye regarding nose wheel undercarriages, it only remained for him to thank Mr. Hollis Williams for the very interesting diagram he had drawn, which illustrated so well the reduction in skill required to land an aircraft so fitted.

Referring to a remark by Flight Lieutenant Bulman that the ideal position of the main wheels was directly under the centre of gravity, that an aircraft could then be brought in to land at a speed very little above the stalling speed, and that there would be no pitching moment about the centre of gravity, he said that any device which entailed bringing a machine in to land at a particular speed, and especially if that speed were near the stall, added to the standard of skill required on the part of the pilot; the points mentioned in the paper, however, aimed at reducing the standard of skill required. If too high a standard of skill were demanded in our pilots, it would probably lead us into trouble when we had to train pilots in wartime; any devices which reduced the standard of skill needed, were of the utmost value, and we were not justified in setting any of them aside until they had received most serious attention. Whatever advantages and disadvantages there might be in the nose wheel undercarriage from the scientific and technical points of view, the outstanding feature was that it enabled a machine to be landed by a pilot who had not a high degree of skill; better still, we could maintain the present standard of skill and would be able to handle safely, machines which were faster, and which had higher wing loadings, if we used the nose wheel undercarriage.

Whilst he agreed with Mr. Vessey that in theory one would achieve the best results if one could bring an aeroplane in to land at a speed near the stall—it would be landing at a high incidence and the touch speed was comparatively low—he felt again that it meant asking the pilot to do something which was very difficult. He had to fly the aeroplane at a given speed, near the stall, and somehow he had to arrange to be at just the right height over the approach boundary. Without air brakes, that would be very difficult. The pilot could use the engines; but a high degree of skill was required, and in the paper he was regarding the object of the three-wheel undercarriage as being, not so much to enable the pilot to bring the aeroplane in near the stall at the higher wing loadings, but to enable him to bring it in over a larger range of speed without " buying " it.

It was true, as Squadron Leader McKenna had pointed out, that if in the case of a forced landing the undercarriage were down when the aeroplane was gliding, and it had to be pulled up just before landing, one would need a guarantee that the undercarriage would come up in time. The half-way position would lead to serious trouble.

The elongated tail skid, referred to by Professor Hill, was a very good thing to enable the standard of skill to be reduced. The B.L.G. undercarriage was on the same lines. The only difficulty was that a machine with that device was not quite so stable on the ground, directionally, as a machine with the nose wheel undercarriage.

The terms " transition error " and " transition point " were used in the paper merely in order to indicate quickly the matters he was discussing. They were his own invention and did not represent an official opinion; indeed, the opinions expressed in the paper were entirely his own, and were in no way connected with the Air Ministry. He had quite an open mind as to the terms which should be used.

With regard to the suggestion by Squadron Leader McKenna that a machine with the three-wheel undercarriage must inevitably touch down fast, he said the point really was that if there were an error of judgment when a machine was approaching an aerodrome, one had to pay for it when using the conventional undercarriage by a fairly long float, and the machine would not touch down until it had travelled some distance beyond the approach boundary; on the other hand, if a machine with the three-wheel undercarriage came down a little too fast, there was much more chance of redeeming the error. Owing to its high degree of directional stability, a controlled swing could be done, so that there was less chance of hitting the hedge at the far end of the aerodrome; that could not be done so well with the conventional undercarriage, at any rate where the wing loadings were high.

As to irreversibility by damping, he agreed that if the aileron flutter problem could be overcome by other means than by irreversibility, one should adopt such means. It had been suggested from time to time in the past that it might be necessary to use irreversible aileron control, and he had felt that if designers wanted irreversible aileron control it was possible to overcome objections that might be raised by pilots. Therefore, he had introduced it into the paper in order that the principle might be discussed, assuming it had to come.

Up to a point regarding take-off he agreed with Squadron Leader McKenna that there was sometimes an exhausted gentleman in the cockpit. Apart from insisting on a good undercarriage, which prevented pitching fore and aft over rough ground, there was little the pilot could do. It was a designer's problem.

Regarding flap settings for take-off, his experience had been similar to Squadron Leader McKenna's when using split flaps—that is they don't make very much apparent difference to the take-off—but with slotted flaps and variable area flaps the difference was noticeable at once.

In common with any device for stopping the aeroplane, quick reverse thrust airscrews could not be overlooked. Clearly unless change of pitch could be effected almost instantaneously they could hardly be a benefit, and in any case would not help in a forced landing. Squadron Leader Fraser said his dream was of assisting the landing by a device which would be held on the " airframe inventory " and not the " engine inventory."

It was, he agreed, not sufficient to limit the upward elevator movement on aeroplanes whose duty required rapid manœuvre: such aeroplanes would have to be made reasonably safe at the stall in order to guard against the dynamic stall.

He was glad to hear Flight Lieutenant Staniland stress the need for trying to land slowly with the three-wheel undercarriage and draw attention to the need for a tail skid on military types at any rate.

He agreed with Flight Lieutenant Quill that contact with the ground should always be made at the lowest possible speed; and, of course, if full use were to be made of the brakes, they must be designed so that they would not overheat. But the point that the brakes might be the limiting factor was not necessarily an argument unfavourable to the three-wheel undercarriage.

The question of the throttle connection with the air brake was very debatable. He had suggested it in the paper because so many people had said that if the pilot were to be given another lever it should be near the throttle, for the pilot wished to avoid as much as possible the necessity for moving his hand from one place to another. If the pilot wanted a grip on the stick, rather like the present air brake control, he could see no objection to it. The main thing was the principle of the variable air brake; he had mentioned the throttle connection because he had thought that the pilot could bring the machine in with one hand on the stick and the other hand on the throttle. With the throttle connection the technique and the controls used would be exactly the same for the power approach, and for the variable air brake approach, except that the former would be done below and the latter above the basic gliding angle line. Actually he had quite an open mind regarding the ultimate solution of the problem. He did not think that there would be any danger of choking the engine.

Presumably the fear expressed by Mr. Radcliffe was that when using the three-wheel undercarriage we were apt to bring a machine down unnecessarily fast, so that in fact we should not be quite so well off as had been thought. It seemed necessary, therefore, to emphasise again the point made in the paper, that a pilot should aim to bring a machine in as slowly as possible and should use as much lift as possible, *i.e.*, he should not bring the machine in with the nose wheel down, but should hold off. The trouble was that sometimes pilots, who usually tried to come in in that way, found that they had surplus speed, which must be overcome. He often watched landings from his office window, and nearly every time the mistake was that the speed was too great, so that the float

was considerable. With the conventional undercarriage, that state of affairs must be accepted; but the three-wheel undercarriage allowed some tolerance.

Mr. Radcliffe's remarks regarding the Boeing Company's experience were very interesting. There were, of course, limits to what even a nose wheel undercarriage could do in regard to braking, but then braking was but one of its many advantages over the conventional chassis.

The CHAIRMAN, in proposing a hearty vote of thanks to the author for his paper, complimented him on the very concise and practical way in which he had crystallised the various phases of take-off and landing as affected by the higher wing loadings used to-day. The Society welcomed such papers dealing with the user's point of view. There were many papers presented by technicians, scientists, engineers and even aircraft manufacturers, dealing with the things which the user of the aircraft had to do, and it was very interesting to have a paper stating what the user had to put up with when the aircraft was supplied to him. One hoped there would be more such papers, and more discussion.

When full use was made of the three-wheel undercarriage, which apparently was going to bring with it everything required for ensuring safety when near the ground, an immense burden might be thrown upon the tyres by the braking, so that there might be increased trouble due to bursting and wear of tyres, and in consequence we might have to put up with greater weight of tyre equipment than was necessary so far. Then the undercarriage itself would weigh more. Perhaps the most serious consideration of all, from the point of view of military aircraft, was that the front wheel would have to be retracted into the space in which at present other things were placed. There was generally a front gunner or bomb aimer, a navigator, a camera, and perhaps a number of other things. It was already difficult enough to make the necessary provision in the front, and the problem of the designer would not be rendered easier by the necessity of providing space for the retraction of the front wheel.

If the three-wheel undercarriage were so good to-day, why was it ever discarded? Its re-introduction seemed to be contrary to the ordinary laws of evolution. In the early days it had been essential to have something in front to prevent a machine turning over on to its nose when landing. There had followed a period in which aeroplanes had become more controllable and pilots had become more skilled, so that such adventitious aids to landing and taking off were no longer required. Now, apparently, we were coming to a more difficult state of affairs, where high wing loadings called for the provision of larger and larger aerodromes if the machines were to be landed in the conventional way, and where the pilot might be rendered as unskilled and the machine as uncontrollable, relatively, as was the case in 1910; therefore, the three-wheel undercarriage would be necessary. That was rather a reflection on the progress made by the aircraft designer, and also on the education of the pilot.

However, Squadron Leader Fraser had presented a most stimulating paper, which had awakened great interest, and the thanks of the Society were due to him in full measure.

(The vote of thanks was carried with enthusiasm.)

In view of the great interest of the paper, the Chairman suggested that it might be opportune to arrange a meeting in the offices of the Society for further discussion of the paper. He asked those members who desired a further meeting for that purpose to write to the Secretary, so that the extent of that desire could be gauged. (See p. 445.)

CONTRIBUTED.

Mr. N. S. NORWAY (*Fellow*): It is becoming evident that further increases in wing loading will bring them into serious difficulties in the take-off, more particularly if for certain classes of aircraft the principle be established that fuel is either consumed or jettisoned before landing. But the basic reason for the

difficulty is not the increase of wing loading so much as the very low standard of transmission efficiency which they are content to accept for an aeroplane during the take-off run.

An average controllable or constant speed propeller will give about 5 lbs./H.P. static thrust. When the aircraft is moving forward at 5 m.p.h. at the beginning of the take-off run, the thrust horse-power exerted on the aeroplane is approximately $(5 \times 7 \cdot 5/550)$, about .07 horse-power. That is to say, the transmission system is working at the magnificent efficiency of 7 per cent., 93 per cent. of the horse-power of the engine being wasted in churning up the atmosphere.

When the aircraft attains a forward speed of 25 m.p.h. the transmission efficiency is about 30 per cent., and at 50 m.p.h. the efficiency is perhaps 55 per cent.

He stated these facts because he felt that they deserve attention, and should form the subject of research designed to improve the acceleration of aircraft at low speeds. He put forward no constructive proposal; he had designed no mechanism to drive the wheels of aircraft from the engines, nor did he hold patents upon a controllable propeller of variable blade twist and blade area. Nevertheless, he felt that such apparently far fetched expedients should be considered carefully as possible solutions of our take-off difficulty; it is not so many years since controllable propellers and retractable undercarriages were thought to be impracticable on account of their supposed complexity and weight.

It is true that the increase in wing loadings is bringing take-off difficulties upon them once again. But this is only so because they were content to accept for the aeroplane endeavouring to get into the air a standard of transmission efficiency which would disgrace a child's clockwork train.

Mr. J. LANKESTER PARKER (*Associate Fellow*): He entirely endorsed the statement that "landing is the pilot's greatest problem," and this problem will become greater as wing loadings increase, unless some balancing factor comes into being. He did appreciate that the ability to increase drag in variable amounts quickly would be most beneficial in getting rid of the last few feet of height and say, that 30 m.p.h. of speed above the stall which is necessary for a safe approach, in a reasonable distance. The difficulty he saw with the variable drag method of judging the approach is that the rate of descent, which is already higher as loading increases, will be made even more rapid by the addition of drag. In the case of large aircraft, this will be very serious as the time taken to flatten out is considerable. A high rate of descent is particularly undesirable in conditions of poor visibility and when judgment is difficult as when alighting on snow or glassy water. Perhaps a technique of added drag, with the rate of descent kept in close check by the use of engines, could be developed.

In his experience, lift flaps of low drag have a much greater effect on the coming to rest distance from a given height than can be accounted for by the increase of K/L.

Many of the advantages claimed for the tricycle undercarriage are already found in the case of a flying boat which is stable when taxying, maintains a respectable angle at rest, can be swung into wind at quite a useful speed, and "landed" at speeds much above the stall, to reduce by water friction, float resulting from over-shooting. The greatest defect in the tricycle chassis seems to be the risk of failure to stop on slippery surfaces such as wet grass or snow, but some form of added air drag would offset this.

In general, he agreed with the lecturer's remarks on irreversible controls. He felt that some form of partial irreversibility such as is found in the steering gear of all modern motor cars is the ideal to aim at.

Mr. F. F. CROCOMBE (*Associate Fellow*): In confining his remarks to that portion of the paper dealing with the possibilities of the tricycle chassis arrangement, he would like to assert a misapprehension under which a number of the previous speakers seem to have been labouring. The impression is that, if a tricycle chassis is adopted in place of the conventional arrangement, the aircraft

must necessarily be landed at a considerably higher speed. Now there is nothing to prevent a perfectly normal slow landing from being made with this form of chassis. The extra benefit it *does* confer is that it enables the landing to be safely made over a wide range of speed. Furthermore, its great virtue is that, since the machine can be allowed to glide safely into the ground, it removes all fears from night and fog landings. Its exemplary behaviour in cross-wind take-offs and landings might also have an application to deck-landing aircraft.

One speaker referred to the effect of fast landings on tyre wear and the probability of increased power brakes being needed, inferring that the tricycle chassis machine would be difficult to bring to rest under these conditions. In any case tyre wear has always been a problem, and it may be found of benefit to evolve some means to rotate the wheels prior to landing, so that the harsh treatment experienced in suddenly accelerating from rest to a high speed of rotation at the moment when it touches the ground may be avoided. Criticising the second point, on a machine with a normal chassis a valuable portion of the aerodrome is not utilised in landing since the machine is still in the air flattening out. On touching down it is dangerous to apply the brakes hard, in case the machine noses over, until a much later stage in the deceleration run. The tricycle chassis machine can be put down on the aerodrome just inside the boundary without flattening out, from where it can utilise all the rest of the aerodrome for pulling up. Even if it were to make a faster landing, it would come to rest in less total distance under equal application of braking force as it has the benefit of the powerful deceleration over the flattening out distance compared with the normal aircraft.

Mr. E. E. ALDRIN (*Associate Fellow*) : If ever there was a need for an interchange of viewpoints in matters aeronautical between both sides of the Atlantic, it is in the pilot's point of view. The influence of British aviation on the older American pilots was considerable on account of the war. It is particularly refreshing to note what a well known pilot such as Squadron Leader Fraser considers important to-day. It would have been helpful to have had his thoughts referred to specific aeroplanes more or less well known in America, as well as in England, say, compared to the Douglas DC-2 or DC-3.

By strange coincidence, while the writer was in Chicago recently, he discussed take-off problems of the progressively higher wing-loaded aircraft, and on his return to New York he found still another angle presented in the receipt of an advance copy of Squadron Leader Fraser's lecture.

The writer's own experience flying modern aircraft has been limited to those not larger than 8,400 lbs. gross and wing loading of 23.9 lbs./sq. ft. in the Lockheed 12. This only serious concern with high wing loadings in the past has been with landings and take-offs at high altitude aerodromes. This now, when considering the Lockheed 12, seems to have been more a question of power loading on take-offs and air brakes in the form of flaps for landing. Fear of inadequate lateral control in rough air when approaching high altitude aerodromes for landing made it desirable to approach with excess speed, and having no flaps a flat gliding angle was needed. The landing was generally tail high. It seemed that the most delicate problem was to prevent "ground loop." This characteristic was of course a secondary cause from high wing loading. The rudder being adequate for all other needs, it became necessary to depend on brakes to keep the aeroplane headed straight. The nose-wheel landing gear would have been the simplest solution all around.

His discussions in Chicago on high-wing loadings were initiated by Mr. Dean Smith, a senior pilot of the American Airlines, who possibly has the longest experience in commercial flying out of New York. In the last decade he has been flying regularly the Ford Trimotor, the Curtiss Condor, the Douglas DC-2 now the Douglas DC-3. He complained that high wing loadings were more dangerous under icing conditions. More than that, the lateral control was sluggish. He has now read Squadron Leader Fraser's paper, and the writer quotes excerpts from notes made by Mr. Smith:—

"Certainly our modern transports need, and need badly, better lateral control, faster, more positive, more sensitive. The stick loadings are not excessive now, and if one were given better leverage and freer and sounder physical position one believes one could stand even greater force requirements if necessary to get the results desired. This lateral control improvement he felt to be very important. At present, lack of confidence materially affects circling and approach technique, particularly in turbulent air. As regards aileron control, he had had no experience with irreversible ailerons, so cannot comment.

He thought Fraser's discussion of landing technique very sound and complete, and he agreed fully in his hopes for improved and large variable flaps.

As to assisted take-offs, well and good, providing an aeroplane is never put in the air with a load greater than it will safely land immediately, or handle with a single engine under abnormal air and weather conditions.

There can be no question but that a successful nose wheel installation on large transports, coupled with large powerful land brakes, would constitute a great improvement. The question is whether or not, mechanically, it is possible to eliminate danger of shimmy and breakdown.

Fraser does not mention the effect of high wing loadings on the aeroplane's flight characteristics under abnormal conditions, which is a matter that has been of great concern to American airline pilots. The loss of efficiency when in ice or in excessively hot or light air, and its effect on single engine performance under these conditions, also in turbulence, are points which have proved to be very real handicaps, and, he believed, constitute a large percentage of the resistance of the airline pilots to the idea of still higher wing loadings. Pilots do not care in the least how high the wing loading is, as long as the undesirable and unsafe flight characteristics thus far associated with high wing loadings are eliminated."

It appears that assisted take-offs will be necessary in the future. Larger aerodromes already seem required, but economical limits are being approached even in the United States, where there is supposed to be so much space available. Present day engine development work with high octane fuels point to still higher octane numbers required for take-off power than for most economical cruising. In other words, when the compression ratio is raised to get best economy out of a high octane fuel, a still higher value is needed to get the proper take-off power. Of course a compromise can be reached, including resort to multi-stage supercharging, but for long range flying such as trans-Atlantic, cruising consumption of fuel is of the first order in importance. Assisted take-offs could be made with retracted landing gears, and thereby improve the safety of operation in case of engine failure, or else a type of landing skids could be adopted. This would satisfy the problem described by Fraser, who pointed out the desirability of different characteristics for flap combinations in take-off and in landing, insomuch as the landing gear could be fitted to provide the additional drag desired. Most multi-engined aircraft can maintain flight and climb in case of partial engine failure with full load, only if the landing gear is retracted. An auxiliary take-off cart with external power could easily provide this catapulting.

If take-off problems can be divorced from the landing and other problems of flight, these others can be most simply handled. Mr. Fraser has clearly exposed in graphical form, the various factors affecting approach and landing. He agreed that flaps were appreciated more in increasing the basic gliding angle than in reduction of the stalling speed. This is even more noticeable in light wing loadings. A let-down undercarriage with its increased drag was a most effective contribution to this.

Power approach has become a necessity in modern air transport in the United States because of the fussy restrictions made by traffic experts in the amount of bank permitted in approach, as well as time loss. Cranky passengers may have brought on a lot of this. Nevertheless, in the event an engine should fail in the

approach, with the landing gear extended, a most dangerous situation would ensue. Pilots are trained to be mindful of relying on a minimum use of power on approach. He knew of a pilot having been suspended for banking too steeply in approaching landing and later having to apply excessive braking and a power ground-loop to avoid over-running the runway. He wondered if similar action is ever taken in the case of unnecessary reliance on engine power for a comfortable power approach?

It should be brought out more emphatically that flaps should not be changed from down position, to fully retracted, when the aeroplane is near the ground approaching for a landing, as a pilot might be tempted to do in case of going around again or of undershooting and wanting to extend his glide. The loss of lift would be disastrous. Mr. Fraser mentions this, but its importance calls for greater emphasis. It is an important consideration favouring multi-position flaps, so that the pilot would apply the flaps progressively.

Mr. Fraser says variation of drag is identical with variation of throttle setting. That would not be the whole story if the thrust line were a considerable distance from the centre of gravity. Nevertheless, the demonstration made is clever and it is a simplification to consider. In most modern aircraft he is right.

Altogether, he wished to compliment Mr. Fraser on his paper, and express a wish that he might give some practical illustrations by referring to types of known aircraft. More should be heard from men of his experience.

Reply to Written Contribution.

Mr. Norway's statement about transmission efficiencies for take-off is indeed most interesting, and it seems that if aeroplanes of the future are going to be capable of self-contained take-offs as opposed to assisted take-offs, mechanisms, more complicated than even the variable air brake, will have to be incorporated.

I am delighted to hear Mr. Lankester Parker say, when so many are talking in terms of 5 per cent. above the stall gliding speeds, that he does appreciate that the ability to increase the drag in variable amounts quickly would be most beneficial in getting rid of the last few feet of height and say, *that* 30 *m.p.h. of speed above the stall which is necessary for a safe approach,* in a reasonable distance.

In considering rates of descent, Mr. Lankester Parker raises a very important point. At present in order to obtain quick deceleration after crossing the aerodrome boundary, we have to put up with high fixed drag during the approach, and to check the rate of descent by using the throttle. This also leads to difficulties if we have to fly round again, as we find our aeroplane near the ground with maximum drag and somehow have to coax it into the air. The logical thing to do is to make the drag variable and only call upon it when needed to check overshooting, and to be able to get rid of it quickly in an emergency. I do most certainly feel that combinations of drag and throttle in different amounts could be used to produce various rates of descent at various speeds. Drag can be most useful sometimes and a considerable danger at other times, it must, therefore, be controllable.

It is interesting to note the comparison between the flying boat and the tricycle undercarriage.

Regarding Mr. Crocombe's remarks about spinning the wheels prior to landing, I have often wondered whether, if the tyres had some form of tread (as for example the Northrop), it would not be possible to design the tread to be good from the braking point of view, and at the same time offer less resistance to the air at the top of the wheel than at the bottom. I have noticed that wheels which have spats covering all but the lower portion often spin quite fast in flight. Perhaps the addition of a tread may be sufficient to spin even unspatted wheels fast enough to reduce the strain at touch down to a more reasonable level.

With the rest of Mr. Crocombe's remarks, I am in entire agreement, as they all stress points I have tried to bring out in the paper.

First of all I would like to thank Mr. Aldrin for his detailed and interesting contribution to the discussion. I am particularly pleased to note that both Mr. Aldrin and Mr. Dean Smith agree with the general principles I have put forward.

In his opening paragraph, Mr. Aldrin touches on the greatest difficulty that I had in trying to convey the exact sense of my impressions through the medium of the printed word to other people. The difficulty was that, as I am a serving officer, I have to refrain from mentioning any specific types of aeroplanes. It would have been much easier for me if I had been able to do so. I must ask Mr. Aldrin to forgive me, therefore, for not being able to give some practical illustrations by referring to types of known aircraft.

Referring to landing the Lockheed 12 on high altitude landing grounds, Mr. Aldrin says that it was a most delicate problem to prevent " ground loop." The *effectiveness* of an aeroplane, as apart from its aerodynamic efficiency, depends to a greater extent than is often realised by those, who never handle the controls, upon the confidence a pilot has in his aircraft and the extent to which it is liable to play tricks upon him. Few things, to my mind, undermine confidence more than the ever present possibility of a ground loop. It seems very hard that a pilot, who has skillfully approached just clear of obstacles and made a clean touch down, should be faced with the very delicate and annoyingly tiresome task of trying to prevent a ground loop. I can well imagine that this problem probably reaches proportions, on high aerodromes, and in disturbed air conditions, that would try to the limit the patience and courage of the most imperturbable pilots. On the day that brakes became an essential to bring the aeroplane to rest within the aerodrome, was born the need for inherent directional stability on the ground. That need has now grown and matured; and the arguments that once sustained directional instability on the score of the simplicity and constructional advantages attached to the conventional undercarriage, no longer hold good. The nose wheel undercarriage kills two birds with one stone in that it provides ground reactions on touch that hold the aeroplane on the ground instead of throwing it back into the air besides giving directional stability. I am pleased, therefore, to hear that Mr. Aldrin considers it the simplest all round solution to the difficulties he tells us about landing on high aerodromes.

Mr. Dean Smith mentions the very thorny problem of good lateral control at landing and take-off speeds. It is a problem that is very pressing, and will become more so if the thickness chord ratio of wings increases. It has been my experience that some wing aileron combinations, which have shown very good results in standard tests have been seriously wanting in really gusty landing conditions. This question of good lateral control is becoming more important here, where the majority of aeroplanes possess a high degree of directional stability, and accurate directional control is dependent on accurate lateral control.

Mr. Dean Smith's hope for improved and large variable flaps is most gratifying. The ultimate limit of wing loading we can reach with the " three condition " aeroplane (the three conditions being:—Take-off and initial climb, duty, and landing) is lower if the landing drag is obtained from a high drag undercarriage and fixed flap, than if variable drag is provided.

The effect of high wing loading on the flight characteristics of aeroplanes with high wing loading is most important. Flying Officer A. E. Clouston, who has recently broken the Cape record, and is at this moment on his way back from New Zealand, having flown there in four and a half days, has very strong views on this subject, which are in close agreement with Mr. Dean Smith. The subject was not included in the lecture as my experience of really bad conditions is limited.

I am particularly glad to note that in America *pilots are trained to be mindful of relying on a minimum use of power on the approach*. It is a point that is not

stressed here, and may result in pilots getting into difficult positions in the event of partial engine failure, or even momentary hesitation in picking up.

I regret that I have apparently not stressed enough, the vital importance of not retracting the flap beyond its maximum lift position. As a matter of fact I intended to do so, but perhaps my wording was not sufficiently emphatic.

Regarding the position of the thrust line relative to the centre of gravity one of my stipulations was that variation of drag could not be accepted if it entailed a large change of trim.

Finally, I would like to thank Mr. Aldrin very much for his contribution to the discussion. I am sure I would be expressing the views of all of us, who are interested in these problems, when I say how glad we are to hear opinions from America and how much we appreciate the trouble Mr. Aldrin has taken in writing to us to let us know what he and Mr. Dean Smith consider to be some of the problems of high wing loading.

SESSIONAL MEETING.

THURSDAY, JANUARY 27TH, 1938.

Mr. Handley Page, Vice-President, in the chair.

The following lectures, which had been delivered at previous meetings, were opened for continued discussion:—

"THE EFFECT OF WING LOADING ON THE DESIGN OF MODERN AIRCRAFT,"

By H. F. VESSEY, B.Sc., A.F.R.Ae.S.,

and

"HIGH WING LOADING AND SOME OF ITS PROBLEMS FROM THE PILOT'S POINT OF VIEW,"

By Squadron Leader H. P. FRASER, A.F.C., B.A., A.F.R.Ae.S., R.A.F.

Mr. HOLLIS WILLIAMS (*Fellow*): In the two lectures which were under discussion, although high wing loading was the main theme, the tricycle chassis had been referred to and this was no coincidence, as there was a very definite relation between the two.

A simple calculation would show that a machine with 20lbs. to the square foot wing loading could be landed at round about sixty miles an hour. If the wing loading were increased to 45lbs. square foot the same combination would give a landing speed of 90 miles an hour. The tendency with modern aircraft was to increase loading, but this was curbed by the danger of making contact with the ground and to a less extent the danger of meeting obstacles on leaving the ground. When one came to the tricycle chassis, the high speed landing lost practically all its terrors, and there was no doubt that a very considerable increase of speed would result from the use of this development. This came about in two ways. In the first place, distance was saved in making contact on the aerodrome, and in the second place, contact could be made without any high degree of skill or precision.

The definition of the tricycle chassis was any arrangement which on contact caused a reduction of wing incidence to smaller or negative angles. This might be accomplished by three, four, or any number of wheels. The other great virtue which was implied by the term tricycle chassis was the endowment of complete directional stability, and this could only be obtained by an arrangement in which the main and non-castorable wheels were just behind the centre of gravity. He did not propose to recapitulate all the statements that had been made in this connection at the previous lectures, but by way of opening the discussion, he proposed to deal mainly with the benefits to be obtained from the tricycle chassis.

With this type of chassis one had a good view of the ground and complete directional stability. An accelerated take-off could be used. If one engine should fail during the take-off the resultant swing was mitigated. On landing, the element of skill was reduced to a large degree because one had a wide margin of contact speeds, and could have considerable vertical velocity.

These qualities are exactly what is required for carrying out the fog landing, and one of the great advantages of the tricycle chassis is its ability to perform this successfully.

Such a machine also was safe on the ground in high winds. There were the further advantages of passenger comfort and ease of loading.

As for the disadvantages, it was thought that the tricycle chassis would probably lead to an increase in structure weight. This was largely a matter

of chance. It depended whether the rear girder was designed for landing loads or flying loads. If the rear structure was designed for flying loads one had to give away some structure weight by strengthening the front part of the aircraft for the front wheel.

Another disadvantage that was likely to be met with the tricycle chassis was inconvenience of installation on military aircraft. This was due to the nose wheel naturally occupying a portion where one normally wanted to mount a turret, or various items of equipment. This was a difficulty which could be overcome by careful scheming and possibly rearrangement of equipment. Several ways had already been discovered of achieving this which, however, the speaker would not go into on the present occasion.

If one reviewed the long list of advantages obtainable with the tricycle chassis and compared them with the conditions on a normal chassis, the comparison was unfavourable.

The conventional chassis to-day required a three-point technique of landing. It wanted a considerable degree of skill, which skill came easily to the accomplished pilot, but was not so easy to the novice. The normal chassis was directionally unstable; the view on the ground was bad, especially in the case of single-engined machines; brakes had to be used with care, and the machine was dangerous in a high wind. He therefore proposed to shorten his remarks by putting to the meeting as a basis for discussion the following proposition:—That the present three-point technique of landing is fundamentally wrong with any wing loading, and as soon as the necessary steps can be taken it would be an advantage to change over to the tricycle chassis.

Captain BARNWELL (*Fellow*): He should like to begin with an obvious statement:—

The advance made in aeroplane performance during the past few years was due very largely to the great increase of wing loading that had been permitted; in other words, they were permitted now to make an aeroplane of smaller over-all size for the same weight and power.

This reduction of wing size had made the internally-braced monoplane a practical proposition, this in turn had made practicable a large reduction of parasite drag.

But the great increase of top speed had made the variable pitch airscrew necessary to retain reasonable take-off, and the great increase in wing loading and reduction in parasite drag had made wing flaps necessary to retain reasonable landing speed and to steepen the approach.

Both of these (variable pitch airscrew and wing flap) are items, expensive in cost, in weight and in complication. Neither of them in themselves improve performance, if anything they slightly decrease it, because of the added weight, but they are necessary because one has attained high performance.

Now at *best* the tricycle undercarriage is in the same category; it cannot improve performance in itself, it must add cost, weight and complication.

Its advantages had been pointed out very completely by other speakers, many of whom had had practical experience with it. He had listened with interest and trusted that the process of mental digestion was well under way.

He felt, therefore, that he might most usefully participate in the discussion by suggesting the disadvantages, because it was extremely important that these should be realised as clearly as were the advantages.

The front wheel is pure added weight, cost and complication. If it retract, as it must to avoid serious increase in drag, it occupies a space in the nose of the body, which space is quite valuable in civil machines, very valuable indeed in service machines.

On a conservative estimate the fitting of a tricycle undercarriage (instead of the present "conventional" type) would add about 2 per cent. of the total weight of the aeroplane. As the pay load of the modern civil machine (for a range of about 700 miles) is about 20 per cent. of the total weight, the fitting of a

tricycle undercarriage would entail a 10 per cent. loss of pay load. There appears no logical reason to expect better take-off with the tricycle, hence, when take-off is the limiting condition (as is now becoming rather general), it seems reasonable to expect this loss.

With the tricycle undercarriage, owing to the attitude of the machine, considerable air braking was lost, hence considerably more reliance had to be placed on the ground brakes.

Small machines are liable to turn over, because their small wheels and short shock-absorbing travel make the normal aerodrome surface a relatively rough one. So for the small machine, the tricycle undercarriage appears to have definite claims, particularly if performance is not a consideration of primary importance.

But for the large machine, assuming practical steps be taken to improve the shock absorbing and damping properties of the " conventional " undercarriage, assuming that the differential action of the brakes be improved, assuming that the " conventional " tail wheel can be locked central when desired (all of which assumptions are safe ones because they represent merely engineering development, not new experiment), is it not probable that all reasonable requirements could thus be met, and met with inappreciable increase of weight, cost or complication?

Aircraft constructors must try to build what the customer wants, and it would appear that the customer invariably wants best performance and best pay load.

If, as seems probable, the customer insists upon the advantages which the tricycle undercarriage would appear definitely to offer (easier blind take-off and landings), he must accept the disadvantages as well.

One would urge, finally, that one is not stampeded into the tricycle undercarriage without facing up to its cost.

Major GREEN (*Fellow*): He thought that aeroplanes ought to be divided into two classes, one that undertook serious commercial flying and accommodated passengers, and the other for private flying. He wondered how many civil aeroplanes had had an accident on landing at the aerodrome. So far as he knew such accidents were extremely rare, and therefore the only advantage of the tricycle undercarriage would be in very bad weather. If one had to land in fog the tricycle undercarriage might be a necessity. One of the advantages had rather been over-stressed, namely, that one had a view of the ground. That did not apply in the case of a large modern aeroplane.

One other point. It seemed to him that if reliance was placed on the front wheel stopping one from going to the ground, should anything happen to the tyre of that wheel one would be in rather a bad position. If the front wheel were to puncture on landing one would probably be very much worse off than if one had not a front wheel at all.

Commander R. R. GRAHAM (*Companion*): He introduced Mr. Cowey, who, he said, was the inventor of one of the tricycle forms of undercarriage.

Mr. COWEY: He would like to read an extract from *Flight* of June 18th, 1936, entitled " Tail up, Three Pointers." The article stated that the new three-wheel undercarriage had many advantages and the interest of the article lay largely in the fact that it appeared nearly two years ago, before any of the present interest in the tricycle undercarriage was started. It was stated in the article that often the obvious escaped detection. Work had been going on quietly with the object of producing and developing a three-wheel type of undercarriage. The whole equipment, it was explained, was experimental, and the components were made a good deal larger and heavier than they would be if originally incorporated in the design. What caused the aeroplane to balloon off the ground on touching the ground, said the writer, was not so much a rebound as the aerodynamic forces in play afterwards. It was conceivable that with the front wheels in the usual position, a quiet landing with nose down might result in the machine turning over; also landing with the wheels locked or too sudden application of

the brakes might have similar results. To avoid this the front wheels were placed further forward than in the standard machine.

After reading the extract further, Mr. Cowey said that since it was written various experiments had been made with tricycle undercarriages with the wheel in the rear, and he had prepared a few notes on the difference in merit between the two.

The first point was with regard to the centre of gravity position. One was not bothered with these considerations if the wheels were far apart on a wide wheel base. Any alteration in the centre of gravity was counterbalanced by the fact that there was support on either side. The wheel base with a rear wheel undercarriage was much longer than was possible with a nose wheel carriage, and consequently there was greater control of the machine on the ground and more control when landing and in the take-off. The lateral stability on the ground was very important because, on applying the brakes, the load was thrown forward on to the front wheels. If one had a nose wheel, the braking effort was removed from the place where one wanted it, and went on to the other wheel which was unbraked.

The last point was with regard to retractability. In the case of the nose wheel, this presented almost insuperable difficulties. On the other hand, a tail wheel could be retracted into a part of the machine not otherwise occupied.

Mr. B. SHENSTONE (*Associate Fellow*): There was one question he desired to ask. Was it not the case that the tricycle undercarriage with the wheel forward if landed across wind would run into the wind? On landing on a runway it was unlikely that one would land normally directly in the wind. Would there not be a tendency to swerve off the runway? The same was true of landing on the deck of a ship. Would there not be some likelihood of running over the side? He suggested that the tricycle undercarriage with the wheel in front would therefore be a decided disadvantage in such cases.

Mr. ALSTON: On the question of directional stability he was under the impression that some wrong ideas had been put forward by the last speaker. The tricycle undercarriage with castoring nose wheel was stable on the ground and not in the air, so that it tended to steer the aeroplane in the direction of motion of its c.g.; consequently, there was a likelihood that it would stick to the runway or the deck of a ship in spite of a cross wind. This directional stability might be disadvantageous if the ship rolled. With regard to the whole question of why a tricycle undercarriage was wanted, this depended very much on the degree of training and skill of the pilot. He presumed they were correct in assuming that the civil airline pilot was very highly trained, but what about the unskilled private pilot, and what about the untrained man in the Air Force? In time of national stress it might be necessary to place people who were not completely trained in charge of very expensive aeroplanes, and it was for these people that they wanted to encourage the development of methods of really safe and easy landing.

He regretted that in service aircraft and civil ones speed range devices such as slots, flaps, etc., were used far too much to extend top end of the speed range, and he feared this influence with any new device which came along like the tricycle undercarriage. Some advantage could be obtained, not only in wing loading, but also in reduction of landing ground if such speed range devices were applied in a different way. In this way one could meet some of the criticisms of the designer who was worried about weight. If the same amount of extra load made possible by a landing device were carried on the aeroplane, some of it could come into useful load, some into increased engine power, and some into the weight of the undercarriage itself. Even if the undercarriage, as had been stated, did weigh an extra 2 per cent. of the total weight of the aeroplane, it would still enable more load to be taken off by an aeroplane of the same size.

It was necessary to keep a sharp eye upon future developments as to the way in which high lift devices, etc., were used; he presumed that service and airline

interests would be looked after by the responsible authorities, but he felt that the private owners, clubs, and small charter companies would have to look to the R.Ae.S. to see that the right kind of aeroplane was developed for their needs.

Mr. J. K. QUILL (Test Pilot of Vickers (Aviation) Limited): A great deal had been heard about the three-wheeled undercarriage, and he himself thought it a very good thing.

He had had the opportunity of flying a machine which was equipped with one, and he did not think that there was any doubt that it was a great aid to landing, and definitely a useful thing to be included in aircraft. But at the moment there were a lot of aeroplanes in the country with fairly high wing loadings which were not equipped with it, and there were still more on the drawing boards at the present moment with still higher wing loadings and still without the three-wheel chassis. These aeroplanes would have to be landed with their high loadings and " orthodox " chassis and so he thought it was now about time that someone started talking about Squadron Leader Fraser's paper and his system of handling heavily loaded and " clean " aircraft on the approach glide, as so far the discussion had centred entirely on the three-wheel chassis.

Squadron Leader Fraser had been advocating his now well known system of approaching and landing for the last two years. Broadly speaking, it entailed using variable drag as a means of controlling the glide instead of using the engine, or sideslipping, or any of the old methods of getting into a small space. What it really amounted to was this. There were a lot of pilots interested in this question and they could be divided into the sheep and the goats—those who agreed with Fraser and those who did not.

A number of people believed in this business of altering the flaps to suit the conditions; if one was over-shooting one put on a little more flap and vice-versa and he did not doubt that it was becoming now a much more practicable proposition with the introduction of the three-wheeled undercarriage and the Irving balanced flap, but until these were universally introduced it was a dangerous procedure.

A heavily loaded aeroplane should have the maximum amount of drag turned on at 1,000 feet and it should be brought in on the " undershoot " principle with the use of engine.

Although there had been a type of flap designed which allowed alteration of the flap angle without very much alteration of the lift and consequent sinking which is so disturbing if one suddenly let off an ordinary split flap anywhere near the ground, he did not consider it was such a direct and positive form of control as the engines.

Furthermore, if pilots showed that they were able to get aeroplanes into small places solely by these little aerodynamic aids the designers will probably pile on more loading thus making the engine again necessary.

Another point was that Squadron Leader Fraser's system entailed the use of maximum flap angle during the latter part of the glide, and many aircraft with their flaps down to 90° had a very severe gliding attitude, necessitating a sudden great change of attitude near the ground on the flatten out.

This was all right in the daytime; the average pilot could be relied upon to pull the stick back in time, but at night gliding in at this very steep attitude and with a high rate of descent it was no easy matter to flatten out at the right height. It was definitely dangerous, particularly in the Service, with a comparatively large number of not very experienced pilots constantly coming from the training schools, unless the engine was used to flatten the attitude of the machine on approaching the flare path. The effect on the landing light was also important. With a steep gliding attitude the light must be trained to shine a suitable distance ahead for the approach. It would be seen as a patch of light on the aerodrome some yards ahead; with the sudden change of attitude of the machine at the flatten out, however, the light would suddenly chase forward across the aerodrome and finally shine up into the air just when it was most needed.

He therefore thought that the design should be carried out with the fact in mind that the pilot's job was easier at that rather flatter attitude of the machine occasioned by the use of engine; there was then less danger of flying into the ground due to flattening out too late, but at the same time the drag was there to " kill the float " once the engine was finally throttled back.

Squadron Leader D. F. ANDERSON: He had not heard the original lectures on which the present discussion was based, and the point he wanted to make might be covered.

From the Service point of view the nose wheel undercarriage would speed up the training of pilots enormously which, in war time, was the vital factor in maintaining or increasing air power.

Wing Commander ROWLEY: Mr. Williams was a very old friend of his own, and consequently when he told him about the tricycle undercarriage he did not believe a word he said! But he went to Hanworth on a very bad day and had a ride in the apparatus and came away a complete convert, in fact a great enthusiast. He fully agreed that the chief advantage of this device was that it would cut down the time of training, and that of course to those of them in the Air Force was a very important thing. The question whether it was going to make the machines 2 per cent. heavier would not matter very much when it came to quick training in time of war.

There seemed to be a difference of opinion as to which was the better type of the two, whether the one wheel in front or the two wheels in front. He had not flown the latter, but he had flown with the one wheel in front and he thought it most admirable. Even one like himself, who rarely flew, could cope with such a device without the usual quaking one had on going up in the ordinary aeroplane. It would be interesting to know whether any one had had a chance of trying both types. The advantage of this undercarriage, to his mind, was that it might be much easier to land. That could only be found out if one took it and flew, and if anyone was present who had flown both types and could compare the two he hoped he would give the meeting the advantage of his experience as to which was the better.

Mr. VERNON read the following remarks from Mr. R. S. Stafford who, unfortunately, was not able to be present:—

Mr. R. S. STAFFORD (*Associate Fellow*) wrote: It is rather surprising that in a lecture devoted to the problem of high wing loadings, no mention was made of the effects of ground interference upon the characteristics of aeroplanes while " touching down." Experiments in this country, and recently in Japan, show that an aircraft fitted with landing flaps may experience a large change of trim when approaching the ground. This trim change is caused by the effects of ground interference upon the wing and tail characteristics and upon the downwash at the tail. The latter effect is by far the most important and in the case of a low wing monoplane, the change of trim may be as much as 8 degs. of elevator setting, the aircraft tending to become nose heavy on approaching the ground. On a small and lightly loaded aircraft this effect, though unpleasant, is not important, but for a large and heavily loaded aeroplane the change of trim must have an important bearing on elevator design. This change of trim will in general be more pronounced as the lift increase associated with the flaps becomes greater, and the elimination of this trim change on landing is becoming a major design problem.

Dr. G. V. LACHMANN (*Fellow*): In his opinion the points in favour of the tricycle undercarriage as set out by Mr. Hollis Williams outweighed the points which might be urged against it. Assuming that the tricycle undercarriage was the coming thing, he would like to ask a few more detailed questions as to its application. So far there were two types of front wheels used on tricycle undercarriages, the castoring and the steerable type. It would be interesting to know which system was proving the more advisable. While he was in America it was impressed upon him that wobble on the front wheel would be most dangerous.

Since means had been found to cure tail wheel wobble, he would like to know whether the tendency to " shimming " was worse with front wheels than with tail wheels. There were also other questions concerning the longitudinal equilibrium during take-off of an aeroplane with tricycle undercarriage on which it would be interesting to be enlightened. An analysis of the longitudinal equilibrium of an aircraft fitted with a tricycle undercarriage indicated a tendency to instability during the final phase of the unstick run. On such aircraft where the elevators were within the slipstream there was probably always sufficient control to prevent an undesired increase of angle of incidence which might lead to an uncontrolled take-off and a subsequent stall. How would an aircraft behave where the elevators were used in the slipstream?

Mr. P. P. NAZIR (*Associate Fellow*): There had been so much talk about increasing wing loadings, but that no one had mentioned anything about remedying the stalling characteristics of wings, which he thought was directly responsible for loadings applied, and that it was of great importance.

With reference to advantages arising from steep glides, he asked why it should not be possible to achieve those advantages with flatter or slow glides, particularly when slower approaches had the benefit of automatically checking forward speed of the aircraft. Improving visibility, etc., while landing, was, he thought, a matter of clean aerodynamic design.

The demand for more efficient lateral controls for flatter approaches, that is, at larger incidences, could also be fulfilled by simple and yet efficient devices that were in progress. Here he did not wish to divert to aerodynamics, but it seemed practically useless to overlook the fact, or, should he say, not utilise advantages resulting from independent aerodynamic designs, before taking assistance of external mechanical appliances to improve the efficiency of modern aircraft. Such devices became more essential when higher wing loadings were to be used, particularly on tapered wings, and consequently called for close attention to the technique of remedying the stall upon various types of wings. It was important not only to know the whys and wherefores of the wing stalls, but also the simplest form of application of remedy when required.

It seemed to him that the percentage of wing stall was responsible for the amount of loading applied, and they appeared directly proportional to each other, for instance, if a tapered wing stalled, say, at take-off incidences, about 50 per cent., then what was the use of increasing its loading without remedying the stall?

The interesting point about tapered wings was the early range of stalling incidence (which was discussed in his paper some time ago) where, unfortunately, the leading edge slot could not be used as a remedy without disturbing airflow and lift on the front portion of the wing, and therefore the cut slot had to be employed as an all-round successful remedy, without of course breaking the wing profile which improved the efficiency still further.

Squadron Leader Fraser referred to plain split flaps giving way to balanced flaps, etc. Might he suggest that an ideally balanced trailing flap arrangement had been worked out, to act in conjunction with the cut slot with all-round satisfaction? This should be still further improved owing to the full-scale effect.

With regard to the assisted take-off for high wing loading, he wondered why designers should bring in external assistance for this purpose when a great part of it could be successfully done independently on its own. Assisted take-off appeared to him to be the last and final help when everything else within the scope of designers failed to do the work—then and then alone, external assistance should be given. The required assistance in his opinion lay in the best slot flap combination arrangement.

Lastly, he desired to mention that the area increasing trailing flap of the cut slot combination would give a controllable drag variation within landing range of the machine, which was required by modern aircraft.

Many of his experiments had shown that greater flap deflection beyond its aileron movement considerably increased drag of the wing, without seriously affecting the lift.

Mr. W. E. GRAY (*Companion*): He referred to one of the advantages of the nose wheel undercarriage as set out in Squadron Leader Fraser's paper, namely, that owing to a slight negative angle of incidence a higher coefficient of friction was obtained between the wheels and the ground, which produced more rapid deceleration at the beginning of the landing run. He thought the reference there should be to frictional force.

Squadron Leader FRASER agreed.

Mr. GRAY: In Mr. Vessey's paper he stated that they were waiting for various new things, one of them an improved lateral control that could be used when they had full span flaps, and another a wing of variable area. The speaker thought those remarks were typical of the Ministry's attitude to the whole thing. They waited for other people to bring out new ideas. Not only that, but the Ministry made it very difficult for such ideas to be developed.

He said it was all very well for " approved " firms, who could do more or less as they liked, but it was certainly not easy for anyone privately to do work of that kind in this country.

In his Fig. 4 Mr. Vessey dealt with the stability of the two types. He considered that figure to be misleading, because if the brakes were not locked there was a large axle-wise force which the author seemed to have ignored entirely and which in the old type made it still more unstable and in the three-wheel type made it rather better. On the same page as Fig. 4 Mr. Vessey mentioned various factors tending to reduce the landing distance; he was surely quite wrong in attributing the suppression of the flatten-out distance to the fact that there was a three-wheel chassis.

He said that he would now turn to the broader aspects of these papers. At the previous discussion the Chairman had asked why it was, if the tricycle idea was so good, that it had not been revived before—so he could hardly be ruled out of order if he answered that question. He would give two main reasons. The first was that the Air Ministry had imposed so many childish restrictions. These restrictions had prevented him testing the three-wheel idea on full-scale ten years ago in this country, and he found it rather ironical that two Ministry men should come forward at this time of day and praise it, one with a hint that it was of American origin. All praise to the Americans, certainly, for testing and adopting it. Three and a half years ago they accepted the Gorell Committee Report, which was to give back to the experimenter the right to test ideas in flight, but they have not yet implemented that promise. When they took that right away by A.N.D. II in 1932 the Under-Secretary of State for Air said in the Commons that no question of principle was involved.

The second reason was that British constructors were so conservative about looking into or testing out new ideas, and this was a serious obstacle to progress. Either they had not the imagination to see the possible advantages of the new idea, or they had not the financial courage to give it a try. He had tried to interest a very well known civil firm in the tricycle idea ten years ago, without success, though the same firm were now trying an experimental one. He had also tried to interest another big firm some five years ago, with the idea of deck landings on three wheels, but they turned it down flat. It was rather a joke that Mr. Handley Page should have asked why it was that the idea was not adopted earlier, because that firm happened to be the Chairman's own.

Mr. H. C. H. TOWNEND (*Fellow*): He desired to endorse the request of a previous speaker that if there was any pilot present who had had experience of both types of undercarriage it would be very interesting to hear it.

Lieut. Commander R. R. GRAHAM (*Companion*): He had had the good fortune to try out both types, and he supposed, being a service pilot, that he should not attempt to give an opinion favourably one way or the other. But in fact,

even if he were not in that position, he would say that there was really nothing between them. It was a treat to land with either type of undercarriage after having tried for a good many years to make a good landing in the ordinary way. The best advice he could give to any designer was to adopt whichever seemed to fit in best with the requirements of the particular aircraft under consideration.

Two questions had also been asked about deck landing. He was asked whether the nose wheel type of tricycle would cause a machine to go over the side, if it were landing on ship's deck in a side wind, or, similarly, to go over the side of a ship that was rolling. It was difficult to theorise on this point. Practical tests would be better, but for his own part he would rather watch tests than try them.

Either type of tricycle was well worth while, because it helped to make the landing both more sure and easy. It was to be hoped that everyone interested would make every effort to reduce the additional weight which, they were told, the three wheels would add to the machine. If it added only 2 per cent., it was worth while to fit on even now for seagoing purposes. It was hard to see why the weight should not be reduced, for after all, the total shock of landing was the same whether it was distributed between three points or two.

Mr. LUCAS: He wished to know why the engines should not be used for pulling up with an irreversible airscrew.

Captain BARNWELL: There were now two tricycle undercarriages, one with a single wheel in front and one with a single wheel behind. It would be interesting to have a plain statement of the respective advantages.

Mr. H. F. VESSEY: The difference between the B.L.G. type of undercarriage, which was the rear wheel tricycle type, and the other, was bluntly that the rear wheel was on a long strut so that the machine normally ran along the ground with the tail up. The wheels were also farther forward to prevent nosing over. But the main point was that the machine was in the low incidence attitude just as the front wheel tricycle was.

The CHAIRMAN: How do you take off?

Mr. VESSEY: One has, he believed, to accelerate to a somewhat higher speed.

Squadron Leader FRASER: Actually that was not so. With the B.L.G. type the tail could be kept at any desired height by mere pressure on the stick and the aeroplane could be taken off in just as small space as with the normal undercarriage. But this was also true of the nose wheel type he had flown. By pulling the stick back after running a little the aeroplane could be "stalled" off. In common with the nose wheel the B.L.G. type was of great assistance in taking off over rough ground as the rear strut of the B.L.G. type, which kept the tail up and prevented the machine from "bouncing," was a telescopic leg. The leg extended under air pressure and had an oil dash-pot. While taking off over rough ground the stick could be pushed forward. The tail then came up under air pressure in the rear leg, the leg would remain extended and so prevent the aeroplane from being thrown off the ground until one was ready to go off.

Mr. THOMAS: It seemed desirable to make some reference to fog. The three-wheel undercarriage had so far been discussed entirely either from the military point of view or from that of the novice; but it seemed to him that the most important advantage to be obtained from this construction would be that it might make fog landings definitely possible for regular air line operations. He wished that there was some air line man, preferably with pilot experience, who could give his opinion.

Mr. J. E. SERBY: He did not see why the high drag flap mentioned in Squadron Leader Fraser's paper should be considered as in competition with the undercarriage in Mr. Vessey's paper. Looking at the flap first, he gathered that most pilots agreed that the flap should have a high drag, but they were not agreed whether the drag should be variable as well. Flight tests made at Farnborough with a variable flap had shown that was very satisfactory. One speaker had

talked about night landing, but he imagined that any night landing was more difficult than landing by day, and if this device made the landing more simple by day, he saw no reason why it should not make it simpler by night. He had satisfied himself that the hinge moments of the landing flap could be reduced to about one-fourth or one-fifth of the hinge moments of the standard split types, and that should help the designer who was complaining of extra weight and complication. With regard to the tricycle, he did not feel competent to speak, but suggested that the best way to use it was to bring the aeroplane in and try to make a normal three-point landing, keeping the tail wheel well down. Only by this method could full advantage be taken of the available C_L max. to keep down the touching speed. Having made the three-point landing the tail should come up quickly, and full braking power applied.

Squadron Leader NIGEL NORMAN (*Fellow*): There was no question whatsoever that the tricycle undercarriage was going to simplify the question of landing out of wind on the runway. He himself had pointed out in a paper some time ago that the measure of the forces applied to an aircraft by a cross wind landing was simply that required to rotate the aircraft until it was in a line with the runway. The question of using these undercarriages raised an interesting point in connection with runways generally. It made it clear that they were absolutely essential for further development in the technique of flying. He had had a good deal to do during the past few years with the building of aerodromes for civil aviation, but had had great difficulty in convincing the people concerned that the runway was what they ought to build. It seemed an unfortunate situation.

Something had been heard from various pilots about landing with highly loaded aircraft. The size of aircraft seemed to be increasing very much. A thing to bear in mind was the position of the pilot himself in the aircraft. As aircraft get larger it seemed to him that it was quite illogical to put the pilot in the nose of the aircraft far in front of the wing, where he got the least possible chance of seeing what he was doing, and was not helped in his judgment as to his incidence and the clearance with which he was missing obstructions. One of the great problems to-day in airport design was the zoning of the surrounding areas against flying obstructions. When a pilot on board ship was bringing a vessel into harbour he had a place where he could see what he was doing and could see the ship itself as well as the objects near which he was navigating it. It had often seemed to him that the place where the pilot ought to sit was underneath the fuselage, behind the undercarriage. There was plenty of room for him there, and he would be able to see exactly from such a position how he was missing obstructions. In conversation with the most experienced air-taxi pilots he had been impressed by the fact that they would all go for a high wing monoplane as being far easier to negotiate across country in bad weather, and this was, of course, due to the improved view they obtained. He wished that some experienced air pilot would give his opinion as to whether in fact such a position as he had indicated would not be easier.

Mr. NAZIR: What is the angle of the glide in landing with the tricycle undercarriage? He thought it was more necessary to "glide in" at a slow speed and not at a fast speed. After all, he thought that the aircraft had to be brought to a standstill, so there was no use of landing even safely at 80 m.p.h. Nobody desired to land so fast and then come to a standstill, this indeed necessitated the use of immensely powerful air brakes. Lastly, he emphasised the advantages of gliding in at a slower speed and coming to a standstill in a much shorter space.

Flight Lieut. H. St. G. BURKE: If these irreversible aileron controls were going to solve the designers' problems they were at least worthy of full trial. The variable high drag had been very much neglected. He desired to know how powerful the flaps were going to be. A pilot wanted as much drag as he could possibly get, just as the motor driver needed to have at his command more braking power than he had ordinarily occasion to use. He thought it important

that the question of rapidly variable high drag should receive serious consideration, because it reduced the element of skill in the approach to zero.

Mr. BRADBOOKE: He had flown seven kinds of tricycles, among which he included the " Flying Flea," as it had the tricycle feature that the ground attitude did not mean an increase of incidence. As between the nose wheel and tail wheel types he found the former much the more stable directionally. Ground looping could be cured by making the tail wheel steerable, but this merely meant spending too much time, as at present, learning to keep straight before take-off and after landing. Tricycles really needed runways, because the main wing took no incidence till there was enough speed to make the elevators effective; after which most tricycles came off the ground like corks out of bottles. One could not take-off at less than flying speed, but after unsticking the climb could be very sudden and steep. The Stearman-Hammond had limited elevator travel and ordinarily was impossible to stall; a device permissible in a tricycle, which need not be landed at the stall. This same machine was the only one he had found with real variable drag, obtained by operating the last 20° of flap opening with a foot pedal. It seemed to work perfectly.

As for the position of the pilot, he thought there should be two pilots and that the second pilot's position should be below.

Mr. C. M. BARTER: From his own limited flying experience he could affirm the advantage of the far-aft position. Landing from that position, in his opinion, was much easier. He also desired to draw attention to the ordinary motor cycle on which shimmy of a single castoring wheel had been successfully overcome. Front wheel brakes on motor cycles proved perfectly satisfactory, and when one applied brakes on the back pair of wheels of a tricycle the loss of braking effect due to the transfer of load to the front wheel could to some extent be dealt with by braking on all three wheels.

REPLY TO THE DISCUSSION.

Squadron Leader FRASER: Mr. Quill had misunderstood his intentions regarding the application of variable drag to the landing of an aeroplane. Mr. Quill had said that his (Squadron Leader Fraser's) system of approaching entailed the use of maximum flap angle during the latter part of the glide, and that this was dangerous, particularly at night, owing to the high rate of descent. Actually it was to avoid this very danger that he (Squadron Leader Fraser) had advocated the use of variable drag. There were two methods of flattening a glide; one was to use engine thrust to overcome a certain proportion of the drag of the fixed flap, the other was simply to reduce the drag. Mr. Quill was an advocate of the former while the lecturer was an advocate of the latter. There were two occasions when high fixed drag would be dangerous. The first was when, during the last stages of the approach or, perhaps, even just before touching down, a pilot found it necessary to fly round again, as may frequently happen. The second was when a pilot had undershot very badly and had to fly level, just off the ground, for some distance before reaching the aerodrome boundary. If the pilot could not get rid of the high drag quickly on these occasions his plight was rather similar to that of the pilot, who suddenly applied maximum drag at the moment of leaving the ground during take-off. The weight of this argument would be felt with increasing force as wing loadings became higher and the success of the take-off became more dependent upon high lift low drag devices than at present. Fixed drag for landing would set a much lower limit to wing loading than variable drag.

Mr. Quill had said that if pilots showed that if they were able to get the aeroplane into small spaces solely by these little aerodynamic aids, designers would probably pile on more loading, thus making the engine again necessary. But this surely was a very good argument for developing variable drag and the lecturer failed to follow Mr. Quill's reason for using it as an argument against variable drag.

Referring to Mr. Quill's remark that the throttle was a more direct and positive form of glide angle and speed control Squadron Leader Fraser agreed, but said that the variable drag did not eliminate the use of the throttle as a glide angle and speed control, but provided an additional control, which the pilot could use to check any tendency to overshoot, which was by no means uncommon. The lecturer well remembered the occasion when the senior test pilot of a well known firm, who had just been singing the praises of the power approach as against having any form of reserve drag to check a tendency to overshoot, realised that he was going to overshoot the aerodrome and proceeded to skid, swing and sideslip the big twin in a most undignified manner, and just succeeded in pulling up before he hit the hedge at the end of the aerodrome. On climbing out of the aeroplane this well known pilot said with a great deal of enthusiasm for his firm's product, " Did you see I could even sideslip now that the . . . has been modified?" The moral was that even our most experienced twin pilots, who are confirmed " undershooters," are occasionally very glad to have a little reserve drag to help them out, and the average pilot would be even more glad.

The lecturer thought that the most important point about variable drag had been missed by Mr. Quill, in common with several others. This point was that the maximum amount of fixed drag that could be permitted was limited by the necessity for the aeroplane to be able to climb slightly with all the drag on. If the drag was variable this limit no longer applied and a really useful amount of drag could be provided, which would enable the most gross overshooting to be checked, so that the skill required in judging the approach became of a very low order. Safety was doubly assured if the variation of drag was obtained by movement of the throttle, for if the pilot had to open his engines the drag would automatically be removed. Finally, variable drag was of great assistance to a pilot, who had engine trouble and was forced to land.

Captain Barnwell had raised the point that 2 per cent. increase in weight would probably be necessary if a tricycle undercarriage were fitted. His (Squadron Leader Fraser's) object in putting these views forward was largely to get some information from designers. Clearly if, after designers had studied the problem and worked things out, it was found that too much had to be given away on account of weight, complication, increased manufacturing time and expense, such devices for the lowering of the standard of skill in flying could not be fitted. It was, nevertheless, the duty of pilots to put forward their views regarding flying technique. Those responsible for policy would ultimately decide whether or not to adopt suggestions, but before they could do so suggestions had to be made and their practicability and effect on performance, cost and manufacturing time assessed by designers. If a tricycle undercarriage were fitted it might add about 2 per cent. to the weight of the aeroplane, but as it would probably permit a higher wing loading a net gain would result.

One of the speakers had said that the blind landing had been forgotten. But that was one of the main objects of the three-wheel undercarriage and had been stressed in his (Squadron Leader Fraser's) paper. It did greatly simplify the blind landing and night landing, and the undercarriage might well be adopted for that reason alone.

Referring to the question of landing on a runway with the nose wheel undercarriage, he thought Mr. Norman had answered that question for him. The aeroplane tended to go in the direction in which it was drifting.

Mr. Alston had said that they were using these various devices on the top end of the scale too much and should pay some attention to the bottom end. That was to his mind extremely important. He believed that more attention should be paid to the bottom end of the scale because he was particularly concerned with the standard of skill required. An experienced pilot, in flying practice, could land and take-off high performance aeroplanes fairly successfully,

but in war he felt we would be up against questions of standard of skill unless some attention were paid to it now.

The question of the ground effect on the change of trim had been raised. That was another good argument, he thought, for the nose wheel undercarriage. An aeroplane was wanted that would not tend to nose over, and would not be thrown back into the air by ground reactions on touching. On the aeroplanes he had flown he had never found this change of trim very noticeable. It called also for good elevator design and not too heavy an elevator. It was important to avoid too steep a joke displacement curve for the elevator, a feature which had been neglected on some modern types.

The possibility of throwing away the braking effect of the high incidence of the wing at the beginning of the landing run had been raised by several speakers. He had stated in his answer to the discussion on the last occasion that the object of the three-wheel undercarriage was not that the aeroplane should come in with low incidence. The aeroplane should be brought in as near the stalling speed as was safe and comfortable. But as no skill was needed to touch down with the tricycle undercarriage, an aeroplane which had, by error of judgment, been brought in to fast could be " eased " gently on to the ground without any fear of being thrown back into the air and stalled. The ability to put the aeroplane on to the ground and use the brakes without fear of turning over made it much easier for a pilot to tell whether he had any chance of pulling up before the end of the aerodrome than when he was obliged to float across the aerodrome to get rid of his surplus speed before touching down. In the latter case there was a great temptation to open the throttles before reaching a distance from the end of the aerodrome equal to the ground run of the aeroplane. This resulted in pilots going round again needlessly. The tricycle undercarriage would greatly reduce this tendency, especially as the aeroplane would be directionally stable on the ground and a controlled swing could be done (as the speed fell), which increased the effective length of the aerodrome.

Mr. Nazir had suggested that it would be better to use a flatter and a slower glide. He agreed with him. He was not so concerned with the actual gliding angle and speed as with the range of gliding speed and gliding angle that was permissible. Any increase of stability and control at and near the stall would be very welcome by pilots.

Mr. Lucas had referred to the possibility of pulling up with reversible pitch airscrews. Anything that was going to help pulling up after touching down was well worth looking into. The reversible airscrew would have to be reliable and the change from a reverse to a forward thrust would have to be capable of being made almost instantaneously.

Major Green said that he wondered how many civil aeroplanes had had an accident on landing at an aerodrome. But apart from the fact that civil air liners are flown by experienced pilots, who know the aerodromes on which they are landing, Squadron Leader Fraser thought that this had little bearing on the case. The problem was how would inexperienced pilots, hastily trained in war, fare. Since the pilot of the modern military aircraft requires a great deal of training in the operational use of his aircraft it was of vital importance to cut down the time needed to teach him to take-off and land, which, after all, were but means to an end. It is quite useless having aeroplanes with super performances if you cannot train pilots to fly them in time to prevent an enemy getting the upper hand.

The possibility of a punctured front tyre was not a pleasing thought, but a tyre on the compartment principle like those fitted to some armoured cars might minimise the risk.

Squadron Leader Fraser welcomed Mr. Alston's remarks because they showed sympathy with the pilot, and pleaded for a share of the benefits of new devices to be given to the pilot, by using them to keep the standard of flying skill to a reasonable level.

Squadron Leader Fraser was extremely glad to see that Wing Commander Rowley and Squadron Leader Anderson had both emphasised the vital importance of cutting down the time of training in war.

It was interesting to hear Commander Graham's view on the two types of tricycle undercarriages and he agreed that the type best suited to the particular duty for which the aeroplane was wanted should be fitted. For ordinary land aeroplanes directional stability on the ground was of great importance, and for this reason he (Squadron Leader Fraser) was inclined to favour the nose wheel type.

It was interesting to hear Squadron Leader Nigel Norman's remarks. With regard to the position of the pilot in the aeroplane Squadron Leader Fraser said that in changing from small single engine aeroplanes to some of the larger of the bombers he definitely thought that there was a tendency to come in much higher than necessary over obstacles owing to the difficulty of seeing by how much the aeroplane was clear of them. In common with any other ideas for making it easier to touch down near the approach boundary, this suggestion was worth examining.

Regarding Mr. Bradbrooke's reference to tricycle undercarriages needing runways, he thought that could be overcome by a careful positioning of the rear wheels relative to the C.G. and using air pressure in the front oleo leg to assist the elevators in getting the tail down. It was very gratifying to hear that the Stearman-Hammond aeroplane had a foot-operated (air) brake, and that it worked perfectly.

In concluding his reply to the discussion Squadron Leader Fraser referred to Captain Barnwell's plea that we are not stampeded into the tricycle undercarriage without facing up to its cost, and said that he (Squadron Leader Fraser) was indeed most anxious to face up to its cost, in fact to the cost of any reasonable suggestions for helping the pilot. The trouble was, however, that there was a tendency to condemn things before we were really in a position to face up to their cost and weigh it against the advantages to be derived. The division of responsibility in producing efficient and *effective* aeroplanes was fairly clear. The pilot must say what things would help him; the designer must interpret them in terms of cost, increased weight, improved or reduced performance, increased production time, and so forth; finally, those responsible for policy, and who are in a position to know all the factors bearing on the case, must weigh the pros and cons and make a final decision. In putting the pilot's point of view he had endeavoured to meet the pilot's responsibility.

Mr. VESSEY: He found some difficulty in replying to the points raised because some of them had already been replied to twice during the discussion and once by Squadron Leader Fraser. Mr. Hollis Williams, in his opening remarks, had made a very good case for the three-wheel undercarriage, he was probably in a better position to speak than any other designer in this country and the film which he showed at the last meeting was one of the most convincing arguments which could be made for this type of undercarriage.

Captain Barnwell was the chief of those who objected to the three-wheel undercarriage as increasing the weight. The speaker thought that he had made rather an unwise choice in comparing it to V.P. airscrews and flaps as a device which added weight without giving an increase in performance. Certainly the three devices were in a similar class. Although the V.P. airscrew did not in itself give greater top speed it allowed of a better performance because it permitted take-off either with less wing area, thus giving higher speed or, alternatively, it allowed of take-off at a greater weight, thus improving pay-load or range. Flaps also allowed of an increase in performance because they made landing possible at the higher wing loadings. The three-wheel undercarriage was in exactly the same category. It would probably increase the weight of the aircraft, but in increasing the weight it would allow a higher performance to be obtained. First of all, the allowable wing loading would be increased. The speaker had sug-

gested that the increase would be approximately from 30lbs. per sq. ft. to 40lbs. per sq. ft. at landing, and he had not found many who disagreed violently with that prediction. Some put it higher and some a little lower, but the order seemed to be reasonably well agreed. The resultant reduction in wing area would allow of quite an appreciable decrease in structure weight and would give a higher top speed. The higher top speed would necessitate less fuel for a given range, so that the net gain in weight might be quite considerable and would completely outweigh the slight extra structure weight caused by the nose wheel type of undercarriage. The figure of 2 per cent. of the total weight of the machine which Captain Barnwell gave as the increase due to the fitting of the three-wheel undercarriage appeared to be higher than was necessary. It probably referred to a conversion rather than to an aircraft designed for a three-wheel undercarriage. It was agreed that the three-wheel undercarriage would not improve the take-off, but contrary to Captain Barnwell's opinion the speaker's experience was that landing, and not take-off, was the limitation with modern high power aircraft. It certainly was the ultimate limitation if some form of assisted take-off were used.

Mr. Cowey had put the case for the rear wheel type of tricycle undercarriage, and he was pleased to see a representative of the B.L.G. company speaking because that type of undercarriage had not been mentioned before. For general purposes the speaker preferred the front wheel type of undercarriage because it was directionally stable. The rear wheel type was not stable on the ground, and it was less stable than the type of undercarriage used on present day aircraft because the C.G. was further behind the wheels. The advantage of the variable incidence that was possible with this type was, however, quite considerable and in certain types of machine might outweigh the stability advantage of the nose wheel type. He was thinking mainly of machines operating from the decks of ships. It had been pointed out by Mr. Alston that the inherent stability of the nose wheel type had a definite disadvantage there because when the machine rolled the aeroplane tended to run down the slope and go over the side into the sea. That was true, and the rear wheel type was from that point of view considerably better off, although for normal landings it was at a disadvantage. If the rudder control at low speeds was made powerful enough, and it must be made powerful for proper deck landing, he thought that it was possible that the rear wheel type of undercarriage might show to advantage, and of course it had the further advantage that undercarriage retraction in single-engined aircraft was a good deal easier. In the modern twin-engine type for normal use the front wheel tricycle is preferable because of its valuable directional stability. Retraction becomes relatively simple, although in military types it may be necessary to increase the length of the nose to accommodate the front wheel. The difficulty of the reduction of effective track mentioned by Mr. Cowey was not serious in this type because of the wide track that was obtained by mounting the undercarriage on the engine structure.

Mr. Stafford had mentioned the problem of ground effect when touching down. With the conventional type of undercarriage the change of downwash on the tail which gave a nose down moment was in some cases a serious disadvantage as it meant that very powerful controls were necessary to allow of the tail being brought down for a three-point landing. With the three-wheel type of undercarriage this change in downwash was favourable as it would automatically rotate the aircraft into the low incidence position for the touch down. It might therefore be possible in some cases to reduce the area of the tailplane and elevator.

Mr. Serby had raised the point as to how the three-wheel undercarriage should be used. The speaker's own opinion was rather at variance with that of a number of pilots who had expressed their views, in that he would prefer that most of the advantages of the three-wheel undercarriage should be used for increasing performance rather than decreasing the degree of skill required. He could see the pilot's point of view, but being mainly concerned with performance

he would tend to regard it as the principal point for consideration. Probably some view between the two was required. In the film of the General Aircraft machine with the three-wheel undercarriage which was shown at the previous meeting, he had been rather disappointed to notice that most of the landings were carried out at high speeds. He had seen a number of news reels of American machines of the nose wheel type and the landings there were not of that kind. They were much more normal, that is to say, the machine appeared to be brought in fairly slowly, touched down with the tail low and then dropped gently forward on to the nose wheel. That was the type of landing the speaker wished to see, for if attention was going to be paid to high speed landings no appreciable advantage would be gained in landing distance or in allowable wing loading. As a suggestion he would say that a glide in at from 5 to 10 per cent. above the stall was desirable. He knew that 5 per cent. was not at all liked by pilots, but surely it was mainly a question of the controllability of the machine. If by an improvement to the lateral stability at high incidence a slow speed glide could be obtained with whole or partial flattening out, then the advantages to be obtained from the three-wheel undercarriage were quite considerable.

Dr. Lachmann had raised a number of interesting points. As a personal opinion the speaker believed the fully castoring front wheel to be preferable to the steerable type, and he believed that the stable characteristics of the former outweighed the advantage of increased ground manœuvrability given by the steerable type. As regards "wobble" of the front wheel, trouble had been experienced in America, but the latest reports were that this had been cured by allowing slight end float on the spindle. The tendency to instability towards the end of a take-off was no doubt present, and it is conceivable that a bump on the front wheel might throw the machine into the air before it had reached flying speed. It was not thought, however, that this danger was serious, and in normal aircraft the elevator control should be sufficient to check any rotation of this type.

Mr. Nazir had made a very good case for the type of flap which he was developing, and there was little that could be added to his remarks.

Mr. Gray had pointed out that the slow glide on to the ground was not confined to the three-wheel undercarriage. The speaker had never suggested that it was, but the three-wheel undercarriage was considerably better off in that way, because if there was excessive speed there was not the tendency to bounce and rotate to the high incidence position, and subsequently stall, that there was with the normal type. If one hit the ground with a high vertical velocity and a considerable forward speed, there was always the tendency to be bounced up again into the air, and with the normal type of undercarriage the tendency was for the nose of the aircraft to rise, giving an increased lift on the main planes and throwing the machine up into the air and causing a stall. With the front wheel type the nose of the machine would drop because the C.G. was in front of the wheels so that the machine would come to earth again as there was not the added increase in lift. Mr. Gray objected to Fig. 4 of the previous paper.* This diagram correctly represented the loads occurring at the instant of touching down with yaw and brakes on and was not considered to be misleading. As the wheels began to rotate an axle-wise force would certainly be produced, and its direction was such as to strengthen the case for the nose wheel undercarriage.

The CHAIRMAN: They had all listened to two very interesting papers and a very useful discussion by people who had taken part in this work. The discussion had really been between the engineering side and the actual user, and he thought it would be a good precedent if a paper and discussion like this were arranged in every one of the sessions, so that those who flew could discuss matters with those who made aircraft, and those who made aircraft would gain a better insight as to what to do.

A hearty vote of thanks was accorded to the authors.

* "The Effect of Wing Loading on the Design of Modern Aircraft" by H. F. Vessey. B.Sc., A.F.R.Ae.S.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

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(*Prepared by R.T.P.*)

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Sights Employed in Anti-Aircraft Gunnery. (A. Kuhlenkamp, Z.V.D.I., Vol. 81, No. 51, 18/12/37, pp. 1453-7. Eng. Absts., Vol. 1, No. 1, January, 1938, p. 12. Available as Translation No. 600.) (54/1 Germany.)

The author discusses the problem of anti-aircraft sighting, more especially as applied to the use of machine guns and automatic guns up to 0.8in. bore. For the small calibre machine gun the ring sight with its modified elliptical form is most suitable. The theory of the circular and elliptical ring sight is given. For larger weapons with greater range the ring sight is inadequate. The author discusses the three typical French (Le Prieur-Ricordel), German, and Italian (Breda) telescopic bar sights used for medium calibre guns. The main geometry of the problem is outlined in terms of the standard target triangle with apexes at the gun, at the target when sighted and at the target when hit, and the effects of quadrant elevation are qualitatively shown to be as the cosine of the elevation. With regard to larger anti-aircraft guns—2in. and upwards—the author observes that in most armies gun control by predictor methods without sights is used, but that in the smaller countries the usual practice is to use a telescopic sight of high magnifying power and to give verbal orders to the gunlayer from a separate calculating and spotting squad. In the German design illustrated a reflex collimator arrangement is employed, by means of which the eye of the layer is relieved considerably; the " sights " in effect are replaced by an illuminated cross wire or graticule focused at infinity, and this is brought into coincidence with the target.

Forecasts from the War in Spain. (E. Canevari, Army Ordnance, Vol. 18, No. 107, March/April, 1938, pp. 273-280. From the Italian.) (54/2 Italy.)

The following main conclusions are drawn :—

(1) The Spanish war has confirmed the fundamental importance of a sound, well trained infantry, equipped with powerful weapons. The German " Schmeisser " sub-machine gun is an improvement on the standard rifle. An ample supply of hand grenades is essential.

(2) Tanks, whether light or heavy, have failed to produce any useful results.

(3) Heavy artillery can only follow up an attack, if the supply of munition is assured by extensive mechanisation. Co-operation between artillery and infantry is indispensable, but at the same time becoming increasingly difficult to achieve.

(4) Great care is necessary in drawing general conclusions from the use of aircraft in the civil war (small number of aircraft employed, multiplicity of types, lack of trained pilots, lack of bases).

It appears, however, that

(*a*) Modern high speed bombers can generally reach their objective in spite of fighter attack.

(*b*) " Attack " aviation (co-operation with land forces) is very effective and is certain to play a most important *rôle* in any future war.

(*c*) Aerial predominance is more a question of quality (material plus pilot) than quantity.

(*d*) German anti-aircraft artillery has proved very effective.

The Air Force on Trial—Lessons of Abyssinia, Spain and China. (Laurent-Eynac, L'Air, No. 440, 1/3/38, p. 141.) (54/3 France.)

Abyssinia.—It was the Air Force which made the Italian conquest possible in a very short time. Due to the absence of enemy aircraft, the Italians were able to reconnoitre large distances and prepare the way for the advance of land troops. The supply of food and ammunition by aircraft to the troops first practised on a large scale in this campaign, marks a new era in colonial warfare.

Spain.—The outstanding feature is the active co-operation of aircraft during the actual land battle. The bombardment of aerodromes is a most effective method of impeding the enemy. Anti-aircraft guns are effective up to 4,000 m. and make artillery observation by aircraft increasingly difficult.

Finally, speed is the most important factor and slow obsolete aircraft are useless.

China.—The bad strategic position of Chinese aerodromes facilitated their destruction by the Japaneses, who are in complete command of the air. Large scale bombing attacks on towns are effective in terrorising both the civilian and military occupants. Accurate bombing aim apparently only possible in dive bombing.

Sound Ranging of Aircraft with Optical Recording. (French Patent No. 803,586.) (Skoda Work, Rev. de l'Arm. de l'Air, No. 102, January, 1938, pp. 109-111.) (54/4 Czechoslovakia.)

In normal sound ranging, the observer rotates a frame carrying two parallel receivers till the sound reaches both at the same time. The adjustment is thus entirely subjective. In the present patent, the adjustment is carried out optically and it is claimed that highly trained observers are not required. Each microphone circuit feeds a neon lamp through a suitable amplifying circuit, the sensitivity being such that the lamp only lights up at the peak pressure values of the sound to which the receiver is tuned. The light is reflected on to a screen by a rotating mirror, the resultant fringe system being a measure of the sound frequency. The second microphone produces an equivalent fringe system which is generally displaced relatively to the first. The frame is rotated till the two systems overlap. Under these conditions there is equality of phase and the source must therefore be on a line bisecting the receiver frame and situated on a plane containing the acoustic axes of the receivers.

Aerial Warfare in Spain from the Republican Point of View. (C. Sweeny, L'Aerophile, Vol. 46, No. 3, March, 1938, pp. 55-57.) (54/5 France.)

The author accompanied the French General Armengaud on a visit during November and December, 1937.

The following remarks on Franco's air force are of interest:—

(1) The Messerschmitt single-seater fighter is too fast to be manœuvrable and can be beaten by the Russian (Boeing) fighter, although the latter is slower.

(2) The Fiat fighters are vulnerable on account of the exposed position of the fuel tank.

(3) The Heinkel, Dornier and Savoia machines are held in great respect.

The Republican machines referred to are given in the following table. They are mainly of Russian origin, although it is stated that the manufacture of similar types in Spain is making good progress.

Name.	Type.	Engine.	Armament.	Duty.	Speed.
Chato	Boeing	1 Hispano	4 machine guns	Fighter	330 km./h.
Natacha	Breguet	1 Whirlwind	2 " "	Ground attack	200 "
Katchousca	Trait-d'Union	1 Whirlwind	5 " "	High altitude bomber	380 "
Mosca	Low wing monoplane	2 Whirlwind	4 " "	Dive bomber and fighter	440 "

The ground attack on troops is carried out at altitude of only 50 m. and under these conditions the defence measures are very inefficient. The ammunition is mixed and consists in succession of tracer, armour piercing, tracer, a piercing, incendiary, explosive and tracer. Opinion is divided whether the incendiary or the explosive bullets produce the greater moral effect on the troops.

The Variation with Reynolds Number of Pressure Distribution Over an Aerofoil Section. (R. M. Pinkerton, N.A.C.A. Report No. 613, 1938.) (54/6 U.S.A.)

Pressures were simultaneously measured at 54 orifices distributed over the mid-span section of a five by thirty-inch rectangular model of the N.A.C.A. 4412 aerofoil in the variable density tunnel. These measurements were made at seventeen angles of attack from $-20°$ to $30°$ for eight values of the effective Reynolds number from approximately 100,000 to 8,200,000. Accurate data were thus obtained for studying the variation of pressure distribution with Reynolds number.

These results on the N.A.C.A. 4412 section indicate that the pressure distribution is practically unaffected by changes in Reynolds number except where separation is involved.

Notes on the Laminar Sub-layer in Smooth Pipes. (R. L. Stoker, J. Aer. Sci., Vol. 5, No. 4, Feb., 1938, pp. 132-3.) (54/7 U.S.A.)

It is generally believed that a laminar sub-layer always exists in the immediate vicinity of all solid boundaries of fluid flow systems. Although the thickness of this layer may be exceedingly small, it nevertheless plays an important *rôle* in the dissipation of mechanical energy by fluid friction, in heat transfer, and in explaining the distinction between hydraulically smooth and rough surfaces.

For any particular flow system, the thickness of the sub-layer would be expected to fluctuate with time and position along the boundaries due to eddies rolling up and leaving the laminar layer. The author attempts to derive an expression for a sort of average thickness with special reference to flow in smooth circular pipes, and to express the rate of energy dissipation within the sub-layer.

A Simple Method for Determining the Aerodynamic Centre of an Aerofoil. (M. J. Thompson, J. Aer. Sci., Vol. 5, No. 4, Feb., 1938, pp. 138-40.) (54/8 U.S.A.)

In presenting experimental data on the aerodynamic characteristics of aerofoils, it is now generally accepted practice to refer the pitching moment coefficients to the aerodynamic centre of the aerofoil section. This point is defined as that about which the moment coefficient is constant throughout the range of angles of attack corresponding to the linear part of the lift curve. The author presents a simple method for locating exactly the aerodynamic centre of an aerofoil directly from wind tunnel test data, all that is required being the lift and drag characteristics and the moment of the air reaction referred to some known point.

An Integrator for Evaluating the Downwash from a Span-Load Curve. (A. Sherman, J. Aer. Sci., Vol. 5, No. 4, Feb., 1938, pp. 148-50.) (54/9 U.S.A.)

The purpose of this paper is to describe a mechanical integrator that derives the downwash distribution directly from a span-loading curve for any particular wing. Such a machine finds its application in checking span-load distributions that may have been either obtained by a Fourier series analysis or assumed in the process of an example of the iteration, or successive approximation, method.

In use, the integrator is set to the spanwise station for which the downwash is desired, a tracing pointer is run over the loading curve from wing tip point to wing tip point, and the value of the downwash is then read directly from the instrument. The distribution of downwash thus obtained, together with the geometry and attitude of the wing and the aerodynamic characteristics of its profiles, produces a new or check loading curve that should agree with the one from which it was derived, providing that that curve be the true span load distribution for the wing.

Problems of High Speed Flight as Affected by Compressibility. (C. N. H. Lock, J.R. Aer. Soc., Vol. 42, No. 327, March, 1938, pp. 193-228.) (54/10 Great Britain.)

Both the lift and drag of an aerofoil undergo considerable changes as the relative speed of flow increases. Depending on the curvature of the body, the local velocity of sound may be reached over certain regions whilst the main flow is still subsonic. As soon as this occurs, the flow pattern changes completely due to the formation of discontinuities (shock waves). The resultant change in pressure distribution accounts for the decrease in lift observed, whilst the entropy loss in the wave together with increased boundary layer loss determine the increase in drag.

In the case of subsonic flow it is easy to calculate the local velocity at any point of a simple contour (ideal incompressible medium), the velocity at infinity being known. Making certain reasonable assumptions the calculations can be extended to include compressibility, *i.e.*, the minimum speed at infinity can be calculated which will correspond to the local velocity of sound at the critical point of the boundary. This minimum speed is called the shock stalling speed and presents a limit to the speed range of orthodox aircraft. It is interesting to note that whilst in pure supersonic flow thin sharp edged aerofoils are required, in the region of mixed flow ordinary streamlined shapes with blunt noses are to be preferred. From a general survey of the problem the author concludes that with ducted engine cooling, aircraft speeds of the order of 500-600 miles should be possible with more or less orthodox designs before the compressibility effect become marked.

(A more extended bibliography containing references to Italian and German work would have been of interest.)

Model Tests on Road and Rail Vehicles, with Special Reference to Testing Under Water. (B. Finzi-Contini, Rendiconti Reale Instituto Lombardo, No. 70, Dec., 1937, pp. 405-28. Eng. Absts., Vol. 1, No. 1, January, 1938, p. 8.) (54/11 Italy.)

The author observes that at high speeds the aerodynamical portion of the resistance becomes predominant and calls for special study in order to enable the best forms of streamlining to be determined. Such study on full-sized vehicles is difficult and model experiments relying on the principle of similarity are generally preferable; but in this case (unlike research on aircraft) it must be remembered that the resistance is affected considerably by the relationship and proximity of the underside of the vehicle to the road surface or rail bed, and according to whether the latter is in a cutting or tunnel, on a raised bank, etc.

The author describes how such experiments may be made using a stationary model in a wind tunnel (*a*) over a fixed base; (*b*) over a moving belt representing the relative motion of the roadway; (*c*) with a second model placed in the position of a looking glass image to the first; but he explains that all these methods—especially (*a*)—are defective. He discusses experimental work on moving models, developing the relevant mathematics and presenting a graph of the aerodynamical resistance to the motion of a cylindrical body expressed as a function of the Reynolds number in the surrounding fluid. From these considerations he deduces the possibility and advantages of making the experiments with models moving along a model track (of any desired cross section) placed under water in a ship-testing tank.

On the Velocity and Temperature Distribution in the Turbulent Wake Behind a Heated Body of Revolution. (S. Tomotika, Proc. Roy. Soc., Series A, Vol. 165, No. 920, 18/3/38, pp. 53-64.) (54/12 Japan.)

In the present paper, Taylor's modified vorticity transport theory of turbulence is applied to the calculation of the velocity and temperature distributions in the turbulent wake behind a solid of revolution which is placed in a uniform stream such that its axis of revolution is parallel to the direction of the undisturbed velocity.

In order to carry out the calculation, it is assumed, with Prandtl, that for sufficiently high Reynolds numbers and at a sufficient distance downstream, there is geometrical and mechanical similarity in different sections of the wake and that the values of the mixing length at corresponding points in different sections are proportional to the breadths of the sections. Also, the isotropy in turbulence is assumed.

Assuming the mixing length to be constant over any one section, the distribution of mean velocity is first calculated and the result is compared with the results of Schlichting's and Simmons's observations. The agreement between theory and observations is not quite satisfactory.

Next, the distribution of temperature is calculated. However, the comparison of the theoretical result with observations is not made, because no measurements of the distribution of temperature in the wake behind a heated body of revolution have yet been made.

Application of the Modified Vorticity Transport Theory to the Turbulent Spreading of a Jet of Air. (S. Tomotika, Proc. Roy. Soc., Series A, Vol. 165, No. 920, 18/3/38, pp. 65-72.) (54/13 Japan.)

The turbulent spreading of a jet of air emerging from a small circular aperture is discussed on the basis of Taylor's modified vorticity transport theory of turbulent motion. Assuming the isotropy in turbulence, the distribution of mean axial velocity is calculated for any one section of the jet whose distance from the aperture is great in comparison with the diameter of the aperture. The calculated curve is compared with the Göttingen measurements and a fairly satisfactory agreement between theory and observations is found (as in the case of Tollmien's calculation on the basis of Prandtl's momentum transport theory).

An Experimental Determination of the Spectrum of Turbulence. (L. F. G. Simmons and C. Salter, Proc. Roy. Soc., Series A, Vol. 165, No. 920, 18/3/38, pp. 73-87.) (54/14 Great Britain.)

The time variation of velocity at a fixed point in a turbulent airstream is analysed into a spectrum. The method adopted involves the use of the ordinary hot wire technique to produce changes of potential in a Wheatstone bridge circuit, which are magnified by a valve amplifier. The fluctuating voltage drop generated

across a resistance in the output circuit of the amplifier is then applied, in turn, to electrical filters having different cut-off frequencies. In each case the output current is measured with and without each filter in circuit, by means of a thermal milliammeter which indicates the mean value of the square of the current supplied to it. From the ratios of the readings taken with and without each filter, the spectrum curve is calculated by a method described in the appendix.

All measurements were made in a wind tunnel, at a point in the airstream where the turbulence created by a grid of regular mesh was known to be isotropic; the wind speeds used were 15, 20, 25, 30 and 35ft./sec.

Experimental Method for Studying Aerodynamic Ground Effect. (L. Viaud, Comp. Rend., Vol. 206, No. 11, 14/3/38, pp. 817-819.) (54/15 France.)

The proper study of ground effect in wind tunnel tests requires the provision of a moving belt. As this presents considerable experimental difficulties, the ground is often represented by a fixed plane boundary in close proximity to the model. This, however, introduces serious sources of error due to thickness of boundary layer if the model is placed some distance downstream from the nose of the boundary. On the other hand, if the model is placed near the leading edge, the flow is deflected and no longer follows the plane contour. The author overcomes this difficulty by placing a second model below its boundary in a position corresponding roughly to that of an optical image. The second model is adjusted till the static pressure on both sides of the plane boundary is the same and the measurements carried out on the original model can then be used to give the true ground effect. The second model need not be an exact replica of the first, its sole duty being to smooth out the flow along the plane boundary.

Graphical Determination of the Resistance Coefficient and Hydrodynamic Moment Acting on a Hydroplane Fitted with Wings and Determination of the Test Wing Setting. (E. Lorenzelli, L'Aerotecnica, Vol. 18, No. 1, January, 1938, pp. 64-77.) (54/16 Italy.)

The behaviour of a flying boat or float seaplane when " on the step " during the take-off process is difficult to study by means of tank tests. The author describes a graphical method for determining the resistance coefficient of a boat under these conditions assuring a certain altitude trim and velocity. The wing setting giving least total resistance is determined and the requisite aileron movements to facilitate take-off are deduced in so far as they affect the hydrodynamic moment and the natural attitude of the boat.

The results are given in the form of general characteristic curves which enable ready application of the experimental results to full-scale conditions.

A Preliminary Investigation of Boundary Layer Transition Along a Flat Plate with Adverse Pressure Gradient. (A. E. von Doenhoff, N.A.C.A. Tech. Note No. 639, March, 1938.) (54/17 U.S.A.)

Boundary layer surveys were made throughout the transition region along a smooth flat plate placed in an air stream of practically zero turbulence and with an adverse pressure gradient. The boundary layer Reynolds number at the laminar separation point was varied from 1,800 to 2,600.

The test data, when considered in the light of certain theoretical deductions, indicated that transition probably began with separation of the laminar boundary layer.

The extent of the transition region, defined as the distance from a calculated laminar separation point to the position of the first fully developed turbulent boundary layer profile, could be expressed as a function of the Reynolds number. Some speculations are presented concerning the application of the foregoing con-

cepts, after certain assumptions have been made, to the problem of the connection between transition on the upper surface of an aerofoil at high angles of attack and the maximum lift.

Flow in Smooth Straight Pipes at Velocities Above and Below Sound Velocity. (W. Frossel, Forschung, Vol. 7, March-April, 1936, pp. 75-84. Available as Translation T.M. 844.) (54/18 U.S.A.)

The flow conditions in smooth straight pipes at high air velocities are investigated. A relation is obtained between the quantity flowing through unit area, the pressure gradient along the pipe and the pipe length.

The friction coefficient λ is determined and compared with previous measurements of incompressible fluids. It appears that for high flow velocities the laws of Nikuradse may be applied to compressible fluids.

The velocity distributions over the cross section of the pipe were measured with a pitot tube and agree essentially with those previously obtained for incompressible fluids.

Finally, the behaviour of the compression shock in a smooth cylindrical pipe was investigated. The compression shock can occur at any position in the pipe, depending on the throttling downstream and travels upstream with increasing throttling up to the pipe entrance, so that thereafter only subsonic velocities occur in the pipe.

The Estimation of the Rate of Change of Yawing Moment with Sideslip. (F. H. Imlay, N.A.C.A. Tech. Note No. 636, February, 1938.) (54/19 U.S.A.)

Wind tunnel data are presented on the rate of change of yawing moment with sideslip for tests of nine complete aeroplane models, 20 fuselage shapes, and three wing models with various combinations of dihedral sweepback and twist. The data were collected during a survey of existing information, which was made to find a reliable method of computing the yawing moment due to sideslip. Important errors common to methods of computation used at present appear to be due to large interference effects, the investigation of which will undoubtedly require an extensive programme of systematic wind tunnel tests. At present it is necessary to place considerable reliance on past design experience in proportioning an aeroplane so as to obtain a reasonable degree of directional stability.

Nearing the Stratosphere. (D. W. Tomlinson, J. Aer. Sci., Vol. 5, No. 4, February, 1938, pp. 125-131.) (54/20 U.S.A.)

High altitude flights were carried out in a Northrop Gamma aircraft fitted with a Cyclone engine (500 b.h.p.) and exhaust driven supercharger. The object of the experiment was to determine

(*a*) The best method of supercharger control for operation at 30,000 feet.
(*b*) To determine the actual increase in speed with altitude.
(*c*) To check computed true air speeds by actual speed measurements at 30,000 feet.
(*d*) To make meteorological investigation at altitudes of the order of 30,000 feet (strength and direction of wind at the base of the stratosphere).

As there was some doubt as to the accuracy of the reduction of indicated air speeds at high altitude to true air speeds, a direct check was made by flying a triangular course at 30,000 feet, the turns being made under wireless control. The results substantiated the method of reduction and indicated an increase in true air speed of the order of 36 per cent. between sea level and 30,000 feet for the same engine power output. Cross country flights at 30,000 feet showed that very little is known about meteorological conditions at these altitudes and extensive research is recommended.

Wind Tunnel Tests on a Low Wing Monoplane with Propellers Running: Longitudinal and Directional Stability, Elevator Hinge Moments. (S. S. Miller and W. H. Albach, J. Aer. Sci., Vol. 5, No. 4, February, 1938, pp. 141-147.) (54/21 U.S.A.)

The model used was to one-sixth scale, the propeller being driven by a 12 h.p. electric motor giving the same linear velocities of the blade elements as in the full-scale aircraft. Under these conditions, the slipstream effects should closely resemble those existing on the actual aircraft.

It appears that the effect of power on static longitudinal stability (free elevator) consists of two parts—

(1) A change in the slope of the tail moment coefficient curve;
(2) A change in the intercept for any given change of tab angle from the neutral position.

A change in rudder angle does not affect the directional stability appreciably; the latter is, however, markedly increased if the engine is operating ("power on").

The Activities of the U.S. Army Air Corps during 1937. (Inter. Avia., No. 526, 16/3/38, pp. 1-3.) (54/22 U.S.A.)

The following are some of the principal lines of development:—

1. Nose wheel landing gear.
2. Stability of tailless aircraft.
3. Radiators placed inside the wings.
4. Full feathering propellers.
5. New chrome molybdenum nickel alloy for valve steels.
6. Automatic recharging device in case of malfunction of aircraft gun.
7. Automatic landing devices.
8. Gyro magnetic compass.
9. Gyro stabilised drift meter.
10. Position line computer.
11. Individual lighting of instruments.
12. Colour photography.

Tank Tests of Model 36 Flying Boat Hull. (J. M. Allison, N.A.C.A. Tech. Note No. 638, March, 1938.) (54/23 U.S.A.)

N.A.C.A. model 36, a hull form with parallel middle body for half the length of the forebody and designed particularly for use with stub wings, was tested according to the general fixed trim method over the range of practical loads, trims and speeds. It was also tested free to trim with the centre of gravity at two different positions. The results are given in the form of non-dimensional coefficients.

The form of model 36 has many of the characteristics favourable for low hump resistance: Rather small dead rise; moderate angle of afterbody keel; moderate depth of step; long, straight forebody undersurface and high length beam ratio. Several of these features, involving the position of the afterbody with respect to the forebody, affect the resistance at high speed adversely when they improve it at hump speed. Good all-round performance depends upon adjusting the various factors until a satisfactory compromise is reached. Each flying boat design requires a different compromise. If the total air-plus-water resistance of a contemplated design using the hull form of model 36 gives a critical condition of excess thrust at high speeds with a large amount of excess thrust at hump speed, then the afterbody clearance could be increased to improve high speed performance at the expense of hump speed performance.

Model 36, in common with most conventional hulls, has a tendency to trim higher than best trim at the hump for practical positions of the centre of gravity.

Unpublished skeleton tests of the model with stub wings show that the stubs act to reduce the trim and the spread between free to trim and best trim. Further tests with various stubs and stub positions are contemplated.

Aircraft Efficiencies. (N. A. V. Piercy, The Engineer, Vol. 165, No. 4290, 1/4/38, pp. 374-376.) (54/24 Great Britain.)

The following are the author's main conclusions:—

1. The fixed wing is the most efficient lifting device at high speeds.
2. Although more research is required on form drag, the efficiency of wings can be calculated with fair accuracy.
3. Greatly increased wing loading increases efficiency and speed and makes large sizes possible.
4. Kinetic energy losses are becoming less important and aspect ratio may be reduced in large fast aircraft.
5. The efficiency of aeroplanes is rapidly approaching the optimum possible, unless major inventions intervene.
6. Much larger power units are predicted in the near future and the Diesel engine may come into favour for long range aircraft.

Supercharging a Pressure Cabin Aeroplane. (A. H. Johnson, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 175-180.) (54/25 U.S.A.)

The paper refers to sub-stratosphere flight tests carried out on a Lockheed XC-35 aircraft built for the U.S. Air Corps. This machine is driven by two 500 b.h.p. Wasp engines, each provided with two exhaust driven superchargers. One of these superchargers is connected to the passenger cabin whilst the other provides the engine charge. The cabin supercharger could be connected in series or parallel. Pressure and air flow control was obtained by throttling the cabin supercharger intake and varying the size of the discharge opening. This adjustment had to be carried out by hand since a satisfactory automatic control is not yet available. A number of flights were carried out at altitudes up to 30,000 feet, the cabin pressure being maintained at the value corresponding to 10,000 feet. Although the tests have demonstrated the feasibility of supercharged cabin operation, considerably more experience will be wanted to render the scheme a commercial possibility. The development required is classified as follows:—

(1) Improvement in intercoolers for the engine superchargers.
(2) Replacement of exhaust driven cabin supercharger by gear driven types.
(3) Reduction in vapour pressure of fuels.
(4) Overcoming icing difficulties on windows.
(5) Improvements in hydraulic auxiliary systems so as to be less affected by cold.

Structural and Mechanical Problems Involved in Pressure (Supercharged) Cabin Design. (J. E. Younger, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 181-5.) (54/26 U.S.A.)

This paper is a summary of the principal features of the laboratory investigations carried out at Wright Field during 1935 and 1936, on pressure cabins, the results of which formed the basis of the specifications of the first practical sub-stratosphere aeroplane, the Air Corps Model (Lockheed) XC-35. While these investigations have sufficient historical interest to make their presentation worth while, their principal value, however, lies in the fact that they were of a fundamental nature, and regardless of the perfection of the art, the principal results will still be applicable to the design of pressure cabin aeroplanes.

The Trend Towards Higher Altitudes in Commercial Air Transport. (W. B. Klemperer, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 186-8.) (54/27 U.S.A.)

The structural problems of pressure cabins are readily reduced to well known principles so that they can be treated either theoretically or experimentally and they do not seem to obstruct the attainment of high flight altitudes in air transport. It seems that the immediate future of commercial higher altitude flying will be a step-by-step development: First, oxygen for the crew to ensure their mental alertness and protect them from insidious and accumulative effects of oxygen privation; second, " low-level air conditioning " oxygen service to passengers; third, pressure cabin supercharged to fractional pressure differential, without fully supercharging the engines; fourth, pressure cabin with supercharged engines. A gradual increase of ceiling would naturally accompany this development.

Helium versus Hydrogen in Airships. (G. Fulton, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 208-210.) (54/28 U.S.A.)

After making due allowance for such factors as water recovery and superheat of the gas, the author concludes that the operating costs of a helium ship will exceed that of the equivalent hydrogen ship (same pay load) by about 10 per cent.

Reference is made to the possibility of discovering some dope which might reduce the inflammability of hydrogen and thus give a new lease of life to this gas for airship operation.

A certain measure of success has already been achieved by the use of tin compounds. Unfortunately these chemicals also reduce the lift, but the possibility of obtaining a commercial solution of the problem must not be ruled out.

Interference of Wing and Fuselage from Tests of 18 Combinations in the N.A.C.A. Variable Density Tunnel Combinations with Split Flaps. (A. Sherman, N.A.C.A. Tech. Note No. 640, March, 1938.) (54/29 U.S.A.)

As part of the wing fuselage interference investigation in progress in the N.A.C.A. variable density wind tunnel, the effects of various split flap arrangements applied to wing fuselage combinations were determined. Split flaps were found to exert their influence independently of the interference, and their effects on the aerodynamic characteristics of rectangular aerofoil combinations appeared to be more or less proportional to their exposed span lengths. The interference, moreover, showed the same character with the split flaps as without them.

Coupled Wing Fuselage Vibrations. (K. Sezawa and W. Watanabe, Aer. Res. Inst., Tokio, Report No. 160, Jan., 1938, pp. 171-94.) (54/30 Japan.)

The authors have studied the nature of the coupled vibrations of the main wing and the fuselage, both of which are of varying mass distribution and cross section, the effect of the concentrated mass at the engine gondola being also taken into account. The mathematical part involves mainly a treatment by Bessel's functions, whilst the experiments deal with the study of the forced vibrations of a celluloid model. Both theory and experiment are in fair agreement as to resonance frequencies, vibrational modes, etc. In the case of symmetrical wing vibration the wing is in a quiescent state at a frequency quite near the resonance condition. The vibrational amplitudes of the fuselage are not generally large. In the case of symmetrical wing deflection, notwithstanding the coupled condition of the wing and the fuselage, it is possible to assume that the half wing span is a cantilever bar and the condition of the fuselage at the wing root corresponding to that of a hinge. In the case of anti-symmetric wing deflection no nodal point exists in the fuselage and the vibrational condition of that fuselage at the wing root corresponds to that of a fixture. In this case only the inertia of the fuselage becomes operative.

Testing Bearing Metals Under Dynamic Loads. (H. O. Heyer, Autom. Tech. Zeit., Vol. 40, No. 22, 25/11/37, pp. 551-9, and No. 23, 10/12/37, pp. 589-95. Eng. Absts., Vol. 1, No. 1, Jan., 1938, p. 17. See also Translation No. 586.) (54/31 Germany.)

The author explains, by means of the usual polar diagram with indexed co-ordinates, how the load varies and shifts in the bearings of internal combustion engines. An improved diagram in three dimensions is added to emphasise the main characteristics of the load variation, and from this he develops the possibility of imitating service conditions in a bearing testing machine. While the bearing is rotating a load is imposed periodically by an oscillating toggle mechanism in which a compact capsule is embodied to measure the load. The eccentric actuating the toggle has an adjustable throw and the load extension characteristic of the capsule plus frame can be calibrated. The author discusses the possible devices available for the capsule, namely, a condenser, a carbon or liquid resistance or an inductance; all three involve indirect and often erroneous measurements; alternatively, use may be made of ferro-nickel alloys giving direct magnetic effects under stress, or piezo quartz with electric charge variations under stress. The last mentioned was used, and the circuits and calibration curves are shown. The author states that it is possible to predict service results after not more than 10 million revolutions in the testing machine. From the studies made so far on this machine he has been enabled to deduce the most suitable general structures of lead bronze, and other bearing metals. In white metal bearings fatigue failure of the more brittle components is a principal cause of bearing failure.

Improvements in the Bearing Qualities of Pistons of Motor Car Engines. (E. Koch, Z.V.D.I., Vol. 81, No. 51, 18/12/37, pp. 1458-60. Eng. Absts., Vol. 1, No. 1, Jan., 1938, p. 9.) (54/32 Germany.)

The author remarks that as pistons are usually either ground or diamond-turned, the surface has grooves at right angles to the direction of friction and these grooves must be worn down in service; he includes a number of photo-micrographs showing the original grooves and the worn surfaces. If the wear is uneven and irregular, the conditions of lubrication and cooling become hazardous and dubious, so that wear is sure to be more rapid and damaging than with even, continuous conditions. From this basis the author gives photo-micrographs of pistons untreated and treated by the electric oxidation process (Eloxieren) and by a newly developed tinning process. He shows that, whilst the untreated piston is subject to strong local corrosion and pitting, the electrically oxidised surface is inclined to seize on account of the harsh erosive action of the oxide on the cast iron cylinder wall, and the consequent lapping action produced by embedded abrasive. The tinned surfaces, on the other hand, show rapid running-in properties and an early stabilisation of a smooth surface which wears but little. The author states that tinned aluminium alloy pistons have been in service in various automobiles since August, 1936, and that with these pistons the running-in time is less than one hour. The tin needed per piston of about 3in. diameter is only about 1.5 gram (1/300lb.) and the time required by the tinning operation, including all preparatory and finishing operations, is only a few minutes.

Theoretical and Experimental Investigation on the Combustion Processes of Spark Ignition and Diesel Engines. (F. A. F. Schmidt, L.F.F., Vol. 14, No. 12, 20/12/37, pp. 640-6. Eng. Absts., Vol. 1, No. 2, Feb., 1938, p. 23.) (54/33 Germany.)

Approximate calculations were made of the time required for, and of the mean temperature increase during, the vaporisation of a droplet of fuel. The author concludes that, even with the very short ignition delay periods observed in oil engines, the greater part of the fuel has already been vaporised when ignition

commences, so that a theoretical relationship between the total ignition delay and the time required for vaporisation cannot be established. The ignition delays observed in closed combustion vessels and Diesel engines are discussed, and emphasises the importance of turbulence emphasised. Diagrams indicate the influence upon the ignition delay of the air density and temperature at the end of the compression period, which materially affect the output of Diesel engines in aircraft flying at great heights. With the object of investigating the " knocking limits " in spark ignition engines, tests were carried out under supercharged conditions with higher charge temperatures at various timings of the ignition and with various excess air ratios. The author discusses in detail his conclusions in regard to the process of combustion and the origin of " knocking."

Mixture Formation and Combustion in High Speed Diesel Engines. (K. Zinner, Z.V.D.I., Vol. 82, No. 1, 1/1/38, pp. 9-14. Eng. Absts., Vol. 1, No. 2, Feb., 1938, p. 24.) (54/34 Germany.)

The author observes that the Diesel is being utilised more and more in the form of small cylinder, high rotational speed engines. With the higher speeds the time available for the formation of a suitable air/fuel mixture is reduced and the difficulties of control and metering are correspondingly increased. The author explains how, by the use of a combustion efficiency and a wall coefficient, the influence of various factors in mixture formation can be determined. The wall coefficient depends upon the cylinder surface per unit volume and upon the heat transfer at the surface; these factors depend upon the effective turbulence. The combustion efficiency depends upon the speed and completeness of combustion, and these in turn depend upon the jet penetration and turbulence in the cylinder. With increase in shaft speeds the energy of mixture formation must increase, and in the calculation of the overall efficiency account must be taken of the mixture-forming energy. At low speeds vigorous turbulence is wasteful on account of the increased heat losses, but with very high shaft speeds and piston speeds the heat losses due to turbulence are more than compensated by improved combustion.

Power and Economy of Mixture Scavenged Two-Stroke Engines. (U. Schmidt, Autom. Tech. Zeit., Vol. 40, No. 24, 25/12/37, pp. 605-613. Eng. Absts., Vol. 1, No. 2, Feb., 1938, p. 23.) (54/35 Germany.)

The author discusses the principal conditions governing two-stroke engine output and economy; the results are presented in graphs, many of which agree closely with the results of calculation. One of the chief factors governing power and economy is the exhaust system. The author indicates two main pressure time characteristics of the exhaust. In one of these the trough of the pressure wave is rounded, the optimum results are confined to a narrow speed range. In the other, with a longer and flatter trough, the speed range for good results is much wider. The flat characteristic is produced by the series coupling of a volume and an acoustic filter through a throttle. If the sound intensity of the exhaust system is plotted on an engine speed basis in phons, the ordinates are substantially constant from 2,000 r.p.m. to 4,000 r.p.m. With no silencer the average reading is about 135 phons; with the usual forms of silencer the mean value is about 120 phons; whilst with the acoustic filter system the noise intensity is about 95 phons. Cross sections of two acoustic filters using glass wool lagging are reproduced.

New Single Cylinder Test Plant of the D.V.L. (W. D. Bensinger, Autom. Tech. Zeit., Vol. 40, No. 24, 25/12/37, pp. 621-3. Eng. Absts., Vol. 1, No. 2, Feb., 1938, p. 22.) (54/36 Germany.)

The author describes the reconstruction of a single cylinder research unit installed in 1933; the alterations made were based upon the experience obtained with the initial unit. The principal features are welded steel construction for

bed-plate and crankcase and a variable compression adjustment by which the cylinder is raised and lowered, after which it is fixed by four stout bolts. Special pumps are fitted, and also two magnetos which can run together with or without separate adjustment, combined with crankshafts giving 110 mm., 124 mm., 130 mm., 140 mm., and 162 mm. stroke; by this means a wide experimental range is rendered available. Either air-cooled or water-cooled cylinders can be utilised. For two experimental cylinders of 130 mm. and 135 mm. bore, with strokes of 130 mm. and 140 mm. respectively, four vertical valves were employed, and also a valve gear based upon sliding helical gears. This valve gear permits adjustment of the valve timing and valve lift during the test. The former valve gear allowed speeds ranging up to 2,200 r.p.m.; the new gear has been found satisfactory at shaft speeds of 3,200 r.p.m. and with valve lifts ranging up to 13 mm. ($\frac{1}{2}$in.).

Heat Transfer Processes in Air-Cooled Engine Cylinders. (B. Pinkel, N.A.C.A. Report No. 612, 1938.) (54/37 U.S.A.)

From a consideration of heat transfer theory, semi-empirical expressions are set up for the transfer of heat from the combustion gases to the cylinder of an air-cooled engine and from the cylinder to the cooling air. Simple equations for the average head and barrel temperatures as functions of the important engine and cooling variables are obtained from these expressions. The expressions involve a few empirical constants, which may be readily determined from engine tests. Numerical values for these constants were obtained from single-cylinder engine tests for cylinders of the Pratt and Whitney 1535 and 1340-H engines. The equations provide a means of calculating the effect of the various engine and cooling variables on the cylinder temperatures and also of correlating the results of engine cooling tests. An example is given on the application of the equations to the correlation of cooling test data obtained in flight.

Soundproofing of Control Cabins for the Testing of Aircraft Engines. (I. Katel, Génie Civil, III, 25/12/37, pp. 544-6. Eng. Absts., Vol. 1, No. 2, Feb., 1938, p. 33.) (54/38 France.)

The author describes control cabins constructed for the French Air Ministry at Bordeaux. The object was that the sound level of the noise from the engines (110-125 decibels, measured at the test bench) should not exceed about 65 decibels in the interior of the cabins. The soundproofing of the walls did not present so much difficulty as that of the doors and windows, and especially that of the numerous small apertures required for the passage of control rods, pipes, cables, etc. The author states that reduction of the area of an aperture in the ratio of 100 to 1 results in a reduction of only 40 per cent. in the physiological intensity of the sound transmitted. Each cabin is situated between two test benches and has two floors, each about 21ft. by 13ft., the control post and all the necessary measuring instruments being on the upper floor. The walls consist of two rows of solid brickwork separated by " katelit " insulating slabs. The ceiling, of reinforced concrete, rests only on the interior rows of brickwork and is covered by slabs of " absorbit," continued to meet the insulation of the walls and protected by a rendering of cement, and by a single-span roof. The upper floor is insulated from the walls, and the walls from the ground, by slabs of " asphalted korsil," and the lower floor is insulated from the ground by a layer of " antiphon." The results of tests made by three different methods indicate an average of 54 decibels as the difference between the sound level near the engine and that inside the cabin.

The Fundamental Principles of the N.A.C.A. Cowling. (T. Theodorsen, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 169-174.) (54/39 U.S.A.)

The cowling performs two distinct functions:—

(1) It provides a streamline enclosure of minimum drag.

(2) It provides a certain pressure difference across the engine.

The nose design of the cowling is not critical. The angle of the front camber line should be of the order of 45° with the axis and the openings as large as is consistent with these requirements.

The skirt design, on the other hand, is rather critical and depends on the engine conductivity* and the pressure difference required across the engine. The skirt edge must neither project into the external airstream nor project inwards. The mean flow line must be parallel to the external flow and some means of changing the exit conductivity must be provided to prevent excessive losses at high speed. This is best done by decreasing the area of the exit slot. At low air speeds, the cooling must be improved either by fitting cowl flaps or providing a nose slot. In either case the proper shape of the propeller boss has an appreciable influence.

Flight Analysis of the Sounding Rocket. (F. J. Malina and A. M. O. Smith, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 199-202.) (54/40 U.S.A.)

The authors calculate the vertical flight in vacuo of a rocket on the assumption of a constant exhaust velocity and neglecting variations in gravity acceleration.

The investigation is then extended to the case of flight through a resisting medium, assuming a variation of the resistance coefficient with speed similar to that obtained with shells.

It appears that in this case there exists a limiting value for the initial acceleration which gives the greatest altitude. A high velocity of flight through the lower strata of the atmosphere causes a rapid consumption of combustible and for this reason it is advantageous to start the rocket at a high initial altitude.

The case of a composite rocket is considered, the lightest element being fired last for which theory indicates a maximum altitude of the order of 1,000 miles.

Media for Overcoming Drop in Power Associated with the Use of Gaseous Fuels in I.C. Engines. (W. Rixmann, Z.V.D.I., Vol. 81, No. 47, 20/11/37, pp. 1357-63. Eng. Absts., Vol. 1, No. 1, Jan., 1938, p. 9.) (54/41 Germany.)

The principal gas fuels used in the experiments were propane, methane, town's gas, and " fluid gas " consisting of a mixture of butane and propane. The tests were made with a lorry engine of 120 mm. bore by 160 mm. stroke, giving a swept volume of 10.85 litres, and a high-speed engine of 79 mm. by 117.5 mm. with a swept volume of 3.49 litres, developing its maximum power at 3,200 r.p.m. The author emphasises the importance of maintaining a high volumetric efficiency. To this end he uses two forms of inlet manifold, one with carburettor and gas mixer in parallel and the other with a series arrangement. Using calorific value, volumetric efficiency, and brake thermal efficiency, he calculates the decrease in power in changing from petrol to gas; the results agree very closely with experiment. The experimental results are presented in tables and curves.

Piston Lubrication. (C. M. Larson, Autom. Eng., Vol. 28, No. 369, March, 1938, p. 105.) (54/42 Great Britain.)

Highly solvent treated oils have been shown to be deficient in lubricating value, and ring sticking caused by excessive blow-by has resulted. Such high output petrol and Diesel engines will operate on straight mineral oils at reduced loads; but reduced cylinder wear, freedom from ring sticking and sludge reduction can be had only with proved addition agents. The highly refined paraffinic base oils plus oiliness addition agents are the most effective for high output petrol engines,

* The engine conductivity is a number expressing the effective free passage area for the air in terms of the nacelle cross-section. For single row radials it is of the order of .065, *i.e.*, in the case of a nacelle 50in. diameter the effect of the engine is similar to that of 250 sharp-edged orifices each 1in. in diameter.

whereas the naphthenic base oils plus entirely different addition agents are best suited for Diesel engines.

High output petrol and Diesel engine research has shown that a lubricant, to reduce ring and cylinder liner wear and give freedom from ring sticking, should consist of a very stable vehicle plus an addition agent which has proper film strength and adhesion, as well as resistance to corrosion and oxidation.

The Viscosity of Hydrocarbons. (E. B. Evans, J. Inst. Petrol. Tech., Vol. 24, No. 171, January, 1938, pp. 38-53.) (54/43 Great Britain.)

During the last half century a large amount of experimental data on the viscosities of hydrocarbons has been accumulated during the course of numerous investigations into the relationship of chemical constitution and viscosity and the dependence of viscosity on temperature. More recently results have been published on some of the hydrocarbons of higher molecular weight and more complex structure, such as might be expected to occur in the higher boiling fractions of petroleum, and especially in lubricating oils.

An attempt has been made here to review critically this mass of data and to present the most reliable and accurate of the results in tables showing viscosities in absolute and in kinematic units at certain standard temperatures, viz., 0°C., 20°C., 50°C., 80°C. and 100°C. The figures tabulated have been obtained by plotting the available experimental data and using the values obtained from these curves.

The results are then readily available for the examination of constitutional or temperature effects on about 150 hydrocarbons, including 38 which have been examined experimentally in the course of this work.

New Measurements of the Velocity of Sound in Free Air. (T. J. Kukkamaki, Ann. d. Phys., Vol. 31, No. 5, March, 1938, pp. 398-406.) (54/44 Finland.)

As an exact knowledge of the velocity of sound in free air is of considerable military importance, fresh experiments were carried out under the auspices of the Finnish military authorities. The sound was provided by the explosion of 1 kg. of explosive fixed on a stake at 1 m. above the surface of the earth and the measurements were carried out with electrical microphones over a base of 1 km. in both directions so as to eliminate wind effects. The first value obtained was 330.77 ± 0.064 m./sec. for still dry air at 0°C.

This applies to the type of sound experimented with (frequency below 1,000/sec.).

For sounds of high frequencies, the author favours the value 331.7 m./sec.

The Application of Aerial Photogrammetry to the Determination of Aircraft Speeds and Training in Bomb Dropping. (M. Niotri, 4th International Congress on Photogrammetry, Paris, 1934, pp. 291-302.) (54/45 Italy.)

A number of vertical photographs of the ground are taken from the aircraft at known intervals of time. The territory must possess a sufficient number of landmarks, the relative position of which is accurately known. From the rectified photographs the position of the aircraft in space at the instant of taking the view can be found and the velocity follows from the known time interval for the passage of a given base.

It is stated that the true ground speed can be determined to within 1 per cent. (the base line being 3 km.) for speeds of the order of 400 m.p.h. at an altitude of 6,000 feet.

The method is also applicable to bomb dropping exercises; one photograph of the ground is taken at the instant of fictitious bomb release whilst a second ground view is taken about 20 seconds later. From these photographs it is possible to calculate—

(*a*) The position of the aircraft at the instant of release.
(*b*) The plane of drop.
(*c*) The speed of the aircraft, *i.e.*, initial horizontal speed of bomb.

The author states that this method is preferable to the alternative of photographing the aircraft from the ground by means of a photo-theodolite. (See also M. Vauzou, 4th International Congress on Photogrammetry, Paris, 1934, pp. 247-90, and C. Bourgues, Rev. de l'Arm. de l'Air, No. 96, July, 1937, pp. 789-98.)

The German Land Plane Speed Record—Details of Measuring Instruments. (W. Rossmann Luftwelt, Vol. 5, No. 3, March, 1938, pp. 88-92.) (54/46 Germany.)

The aircraft passing either end of the 3 km. base is photographed by means of high speed cine cameras situated at right angles to the base. Each camera is provided with a series of counters which are driven at a uniform speed under tuning fork control. The position of these counters at the moment of exposure is recorded on the film and enables the position of the aircraft relative to the ends of the base to be fixed to within 1/1000 sec. (50 pictures per second).

This camera was originally designed by the Reichsanstalt for the Olympic Games and its adaptation for the present purpose created some difficulty on account of the relatively great distance between the two units. The final synchronisation is obtained by means of a standard chronometer and a special low resistance electrical cable.

Shear Distribution in a Sheet Metal Box Spar. (H. W. Sibert, J. Aer. Sci., Vol. 5, No. 4, February, 1938, pp. 134-7.) (54/47 U.S.A.)

Within the last few years many aeroplane designers have become interested in the construction of wings in which the entire bending and torsion is carried by a single sheet metal box spar. One great difficulty in designing such a spar has been the question of shear distribution along a cross section. In the present paper simple formulæ for the shear distribution are given which can be applied to a sheet metal box spar of any shape whatsoever, whether or not the skin contributes anything to the strength in bending. In addition, a simple graphical method for determining the shear centre for such a box spar is given.

Preliminary Fatigue Studies on Aluminium Alloy Aircraft Girders. (Goodyear Zeppelin Corporation, N.A.C.A. Tech. Note No. 637, Feb., 1938.) (54/48 U.S.A.)

Preliminary information on the complex subject of the fatigue strength of fabricated structural members for aircraft is presented in the test results obtained on several different types of airship girders subjected to axial tension and compression in a resonance fatigue machine. A description of this machine as well as numerous photographs of the fatigue failures are given. There is also presented an extended bibliography on the subject of fatigue strength.

Studies of Surface Layers of Materials. (N. N. Sawin, Science et Ind. (Mécanique), No. 21, Nov.-Dec., 1937, pp. 269-75. Eng. Absts., Vol. 1, No. 1, Jan., 1938, p. 13.) (54/49 France.)

The author describes the Skoda-Sawin wear testing machine, in which a disc is rotated and pressed into the surface under test, and indicates that the volume abraded is directly proportional to the number of revolutions of the disc. For hardened steel the rate of wear is approximately 0.5 cu. mm. per 15,000 revolutions. The normal speed of the disc, which has a diameter and width of 30 by 2.5 mm. respectively, is 675 r.p.m. and the test piece is cooled by a stream of 0.5 per cent. K_2CrO_4 solution in distilled water. The wear of the widia disc

is remarkably slight; even after 6×10^6 revolutions, or say 2,000 specific tests of different tool steels, its diameter is reduced by only 0.003 mm. The author concludes that all surfaces of machined or polished materials are under tension and that the tension depends on the past history of the specimen. The surface tension is greater in polished or finished specimens, and the abrasion is correspondingly greater in these polished specimens even to depths of 100 μ. The author ascribes the main variations and the inconstancy of wear effects to internal tensions in the material, and he states that these are greater in polished than in unpolished specimens. In all the tests, using various tool steels variously prepared, no relation between hardness numbers and wear values could be detected.

Analysis of Bolted Joints at High Temperatures. (E. O. Waters, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. A7-10.) (54/50 U.S.A.)

A preliminary study shows that the flanges in a typical bolted joint for piping have a more nearly uniform, and hence more favourable, stress distribution after creep has occurred than when the joint is first tightened up. However, the tightness of the joint depends on the initial elastic stretch of bolts and flanges; hence an estimation of its durability at high temperature is really a compound relaxation problem, and the advantage to be gained by the quasi-uniform stress distribution is apt to be illusory.

Effect of Temperature on Physical and Optical Properties of Photo-elastic Materials. (G. H. Lee and C. W. Armstrong, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. 11-12.) (54/51 U.S.A.)

This paper reports the results of tension tests, to determine the suitability for photo-elastic work, of five samples of Bakelite and two of marblette at temperatures between 32 and 140°F. These results show the variation of Young's modulus, Poisson's ratio, stress-optical coefficient, and strain-optical coefficient with temperature. Stress-strain curves of the materials are also given showing the relative amounts of creep. The effect of heat treatment on marblette is shown by tests before and after annealing.

Rubber Mountings. (J. F. D. Smith, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. 13-23.) (54/52 U.S.A.)

This paper deals with static deflections of rubber mountings. An equation has been developed which correlates all the available data on plain rectangular slabs under compression loading. Data are given showing how closely this equation checks experimentation, and examples are solved, giving the method of using this equation and also the use of a chart simplifying the calculations. Additional data are given on other shapes of compression mountings.

The deflections of shear type mountings are shown to agree with theory. Combination shear compression units have also been tested.

Data are given showing the variation of hardness on the durometer A scale with change of temperature. At room temperature moduli of elasticity for compression and for shear are related with durometer hardness number, and the equations of these curves are derived.

A Rapid Method for the Determination of Principal Stresses Across Sections of Symmetrical Form from Photo-elastic Data. (M. M. Frocht, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. 24-8.) (54/53 U.S.A.)

The author discusses: (*a*) Mesnager's theorem of isoclinics, (*b*) the characteristic curve of tangential stresses across a section of symmetry, (*c*) a formula for the maximum tangential stresses for the case of a central circular hole between fields of pure tension, (*d*) the slope of the p curve at a point corresponding to a cupic point, (*e*) recent improvement in the determination of free boundary stresses, and (*f*) formulæ for the position of cupic points for two cases.

A new method for the determination of the principal stresses across sections of symmetry from photo-elastic data is illustrated with three examples:—(1) Bars in tension or compression with central circular holes, (2) grooved beams in bending, and (3) rings or discs with circular central holes subjected to two concentrated diametral loads.

Creep of Metals at High Temperatures in Bending. (E. A. Davis, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. 29-31.) (54/54 U.S.A.)

The author develops a theory for plastic bending and obtains equations for the creep due to bending. Results of tests on a chromium-nickel composition are given to show the agreement between the experimental and theoretical results.

The Buckling of Curved Tension Field Girders. (G. Limpert, L.F.F., Vol. 14, No. 7, 20/7/37, pp. 356-60. Available as Translation T.M. 846.) (54/55 Germany.)

The author describes reports of experiments on the buckling load under shear of circular curved tension field webs. The buckling load of the webs can be expressed in terms of the buckling load of the stiffeners. Within the experimental range the buckling load is approximately twice as great as that of the identically stiffened flat wall of equal depth of web.

Stresses in Reinforcing Rings Due to Axial Forces in Cylindrical and Conical Stressed Skins. (K. Drescher and H. Gropler, L.F.F., Vol. 14, No. 2, 20/2/37, pp. 63-70. Available as Translation T.M. No. 847.) (54/56 Germany.)

At the ends of a monocoque fuselage concentrated axial forces in the skin must generally be taken up. Such axial forces must also be taken up in the case of other members where axial forces from the neighbouring stressed skin construction must be considered. In order to take up these axial forces two bulkheads or reinforcing frames may be arranged at the positions where the forces are applied. If these bulkheads are in the form of rings, bending moments are set up in them. In the present paper computations are performed for obtaining the value of these bending moments. It is assumed that the stressed skin is cylindrical or conical and that its cross section is circular or elliptical.

Fire Tests on Treated and Untreated Wood Partitions. (C. R. Brown, Bur. Stan. J. Res., Vol. 20, No. 2, Feb., 1938, pp. 217-39.) (54/57 U.S.A.)

Fire endurance tests were made of 13 wood partitions 4ft. square and of four partitions 10ft. high and 16ft. wide. Some of the smaller partitions were of untreated long leaf pine, while the others were made of long leaf pine impregnated with various amounts of monoammonium phosphate up to 17 per cent. by weight. They were built either of one, two, or three plies of $\frac{3}{4}$in. boards, or of a $1\frac{3}{4}$in. core with $\frac{3}{16}$in. veneers, giving a total thickness of $2\frac{1}{8}$in. The large partitions were of the latter design and were made of treated birch. The results of the tests of the small panels are compared with results of fire tube and flame penetration tests made on specimens representative of each panel.

Note on Galerkin's Method of Treatment of Problems Concerning Elastic Bodies. (W. J. Duncan, Phil. Mag., Vol. 25, No. 169, April, 1938, p. 628.) (54/58 Great Britain.)

The method of Galerkin may be looked at from two distinct view points:—

(*a*) As a process for the approximate solution of differential equations.

(*b*) As a means for quickly and easily applying Lagrange's principle of virtual work to problems in the statics and dynamics of elastic and other continuously deformable bodies.

The method is considered from both points of view in No. 1798 of the Reports and Memoranda of the Aeronautical Research Committee, which also contains numerous examples of its applications to such problems as the flexural and torsional oscillations of beams, the critical behaviour of struts, and the solution of linear ordinary and partial differential equations. In the present short note attention is mainly confined to the application of the method to the flexural motion of a cantilever, since this affords an excellent illustration of the principles involved.

Application of the Galerkin Method to the Torsion and Flexure of Cylinders and Prisms. (W. J. Duncan, Phil. Mag., Vol. 25, No. 169, April, 1938, p. 634.) (54/59 Great Britain.)

The paper shows that the Galerkin method can be readily applied to the St. Venant torsion problem and to the St. Venant problem of the flexure of a cantilever under tip load. The following three cases of torsion are treated in detail:—(*a*) Cylinder of aerofoil section; (*b*) cylinder of parabolic lenticular section; (*c*) rectangular prism. It is shown that the solutions obtained by the Galerkin method agree closely with those obtained by other methods. A simple formula for the torsional stiffness of a cylinder whose section is narrow and symmetrical, but otherwise arbitrary, is obtained. This formula is accurate in the case of an elliptic cylinder. It is shown that the shearing stresses in the flexure problem and the position of the flexural centre can easily be found, and applications are made to the elliptic cylinder and to a cylinder of aerofoil profile.

Creep of Metals at High Temperature in Bending. (E. A. Davies, J. App. Phys., March, 1938, pp. 29-31. Metropolitan Vickers Technical News Bulletin, No. 605, 8/4/38.) (54/60 Great Britain.)

The author develops a theory for plastic bending and obtains equations for the creep due to bending. Tensile and bending tests were carried out at 1,500 and 1,652°F. on a chromium-nickel composition. Results of these tests are given for the purpose of comparison with theoretical results. Illustrated with seven diagrams.

Electron Diffraction Applied to Corrosion Study. (I. R. Landau, Metals and Alloys, March, 1938, pp. 63-7. Metropolitan Vickers Technical News Bulletin, No. 605, 8/4/38.) (54/61 Great Britain.)

The view is advanced that prevention of corrosion of metals depends largely on the formation of protective oxide films. Hence it is suggested that the study of such films will yield more useful results than can be obtained by trying out various alloys. Methods of studying surface films by electron diffraction, and Thomson-Fraser and Finch types of electron camera are described. Illustrated with five photographs and two diagrams.

Physiological Considerations Governing High Altitude Flight. (J. W. Heirn, J. Aeron. Sci., Vol. 5, No. 5, March, 1938, pp. 189-192.) (54/62 U.S.A.)

The author considers the effects of reduced pressure and oxygen concentration on the human organism and concludes that high altitude flying becomes only feasible if a sealed aircraft compartment is provided. Such a compartment presents certain physiological problems, such as

(1) Temperature control.
(2) Humidity control.
(3) Ventilation.
(4) CO content.
(5) CO_2 content.
(6) O_2 content.
(7) Absolute pressure.

The first three items on this list should not present great difficulties in view of recent advances in the science of air conditioning. The last four items have been investigated experimentally. It appears that a sudden rupture of the cabin will not be catastrophical, provided that lower levels can be reached before the symptoms of compressed air sickness and anoxemia have time to become manifest.

The Influence of Aviation Medicine on Aircraft Design and Operation. (H. G. Armstrong, J. Aeron. Sci., Vol. 5, No. 5, pp. 193-198.) (54/63 U.S.A.)

An accident attributed to error of judgment of the pilot may be due to any of the following reasons:—

(1) The pilot was not mentally or physically fit.
(2) Inexperience.
(3) Fatigue due to the trying conditions under which the work of pilotage has to be carried out.

Fatigue may be due to noise, lack of oxygen, changes in altitude, or concentration on instruments (blind flying).

The examination for the acceptance of a pilot calls for physical normality in all respects, stability of nervous system and intelligence.

It is very difficult to combine these three desiderata in one individual and the deleterious effects of the conditions under which he has to work cause a rapid wastage.

The human element in flight is the weakest link and progress will only be made if as much care is taken in designing for the pilot's comfort as is at present expended on increasing the pay load.

Some Aspects of Magnetic Recording and its Application to Broadcasting. (A. E. Barrett and C. J. F. Tweed, J. Inst. Elec. Eng., Vol. 82, No. 495, March, 1938, pp. 265-88.) (54/64 Great Britain.)

This paper presents a somewhat simplified consideration of the processes occurring in the magnetic recording of sound on steel tape, and describes some of the apparatus and methods used in this country in its application to broadcasting.

A brief historical account is given of the early uses of magnetic recording. The essential processes involved are then discussed in a simplified form, and the effects of the finite longitudinal spread of the recording field, and of the self-demagnetisation of the tape, are considered before the question of background noise is introduced.

In the next section certain fundamental experiments are described, followed by a brief account of various possible methods of saturating, recording, and reproducing. Considerations relating to the conditions for the optimum working of any particular arrangement are put forward, with the results of tests of two of those which are now in use. Some details are given concerning the tape itself, after which a recording machine is described.

The paper concludes with a short account of the technical and programme service requirements for a recording system for use in connection with broadcasting, and a description of a recording channel at the British Broadcasting Corporation's premises at Maida Vale.

Directional Recording of Radio Atmospherics. (F. E. Lutkin, J. Inst. Elec. Eng., Vol. 82, No. 495, March, 1938, pp. 289-302.) (54/65 Great Britain.)

The paper describes an improved recorder indicating the direction of arrival of transient impulses continuously throughout the day. The polar diagram of the receiver has a width of 20° and is unambiguous. The analysis of three years' records shows that most of the atmospheric disturbance reaching a station in England arrives from the west or south-west, but that during summer afternoons sources to the east and south-east are productive together with storms of a purely

local character. The disturbed azimuths appear closely related to the bearing of the great tropical thunderstorm centres, but the intensity of disturbance from each is dependent on the ionisation conditions prevailing over the path to the receiver, at the time each region is productive. Curves are given from which the probable intensity of atmospheric in any direction at any time may be roughly determined.

Recent Developments in Magnetic Materials. (C. E. Webb, J. Inst. Elec. Eng., Vol. 82, No. 495, March, 1938, pp. 303-24.) (54/66 Great Britain.)

A review is given of recent developments in magnetic materials, including alloys for permanent magnets, "soft" materials having large initial and maximum permeabilities and materials with constant permeability over a wide range of magnetising force. Particular reference is made to dispersion-hardening alloys, the attainment of high degrees of purity in iron and iron alloys, improvements in sheet materials, the properties of nickel irons, and of complex alloys based on them, after various thermal, magnetic, and mechanical treatments, and the characteristics of powdered materials.

Radio Emergency Procedure. (H. W. Roberts, Aero Digest, Vol. 32, No. 3, March, 1938, p. 27, 160-1.) (54/67 U.S.A.)

Recently an air liner carrying passengers on a scheduled 35 minutes flight lost its bearings and had to stay six hours in the air before landing. It appears that the flight crew of a modern air liner is overburdened and can only fulfil their manifold duties so long as all goes well. To prevent a similar emergency arising in future, the author put forward the following recommendations:—

1. Radio operator-navigator should be carried on all scheduled flights in addition to pilot and co-pilot.
2. Improved modern types of aircraft radio direction finders should be carried in scheduled operations.
3. Standardised rules for radio emergency procedure should be promulgated and enforced.
4. Duplication of transmitting equipment on scheduled operations.
5. Ground direction finders for aircraft should be installed at strategic airports.
6. Qualified pilots, familiar with the equipment and the terrain should be on call at ground stations.
7. Standardised radio procedure for aircraft should be under government control.

Direct Viewing Type Cathode Ray Tube for Large Television Images (18*in.* *by* 24*in.*). (I. G. Maloff, R.C.A. Review, Vol. 2, No. 3, January, 1938, pp. 289-96.) (54/68 U.S.A.)

A new device for obtaining large bright television images of high contrast and high definition has been developed at the Camden Laboratories of the R.C.A. Manufacturing Company. It is a direct viewing cathode ray tube 4½ feet long and 31 inches in diameter. It is of the continuously evacuated type and gives a picture 18 by 24 inches in size. The paper describes the design and construction of the new tube, the reasons for the development, the difficulties which were overcome and the results obtained.

A New Principle in Directional Antenna Design. (W. W. Hansen and J. R. Woodyard, Proc. Inst. Rad. Eng., Vol. 26, No. 3, March, 1938, pp. 337-45.) (54/69 U.S.A.)

It is shown that in certain types of directional antenna arrays the gain can be increased by arranging so that waves going from the array elements in the direction of maximum transmission are not strictly in phase at large distances.

Two examples correspond to the kind of directivity generally desired in a broadcast antenna. One of these consists of short antennas placed in concentric rings. A typical array of this type containing 22 short antennæ with the radius of the outer ring equal to 1.39 has a gain of 2.31 as compared with 1.56 for a vertical half-wave antenna. The other example of a horizontally radiating array consists of a single ring of short antennæ. An example of this type is calculated which has a gain of 2.0 with a total of 23 antennas placed in a circle with a radius of 1.43. These figures are not given as the best that can be done, but only as examples.

REVIEW.

AIRCRAFT RADIO.

By D. Hay Surgeoner. Pitman's. 1938. 12/6.

Many books have been published which deal with the design and construction of radio transmitters and receivers. It is rare to find a book dealing with the operation of wireless sets.

Mr. Surgeoner's book is particularly welcome in view of the increasing importance of radio to air line operation, and of the great difficulty of obtaining the information elsewhere. This information is scattered through the "Air Pilot," "Notices to Airmen," "Admiralty List of Signals," and other books. There is still no book dealing completely with air wireless procedure, for Surgeoner does not give a full account of the "Q" Code. Perhaps a future edition will include this.

After dealing with radio networks, wave lengths and communication systems in a very satisfactory manner, the author goes on to describe directional and landing systems. It is here that we are particularly grateful for the first clear and accurate account of this important subject. The Lorenz blind landing system is illustrated by the Heston approach of QDM 273°, which was the first to be installed in this country.

There follows an interesting and well illustrated account of the wireless equipment of aircraft. The pilot will be particularly interested in pages 86-91, dealing with direction finding and homing from the air.

The book is completed by a chapter on airport wireless equipment, again very well illustrated. The last chapter deals with airport and airway illumination. It is well written, but seems singularly out of place. The only excuse seems that these aerial lighthouses come under the general category of "beacons."

The book can, however, be thoroughly recommended as the only one of its kind dealing with wireless operation in the air.

The 629th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, S.W.1 (by permission of the Council of the Institution), on Thursday evening, January 13th, 1938, when a paper on " The Practical Use of Radio as a Direct Aid to the Landing Approach in Conditions of Low Visibility" was read by Squadron Leader R. S. Blucke, A.F.C.

In the chair: Professor G. T. R. Hill, F.R.Ae.S., *Member of Council.*

THE CHAIRMAN: The lecture would deal with what all would agree was a topical subject—flying in bad weather. All they had to do was to look outside the door, across the park, and think what it would be like landing in the kind of weather they saw that night. The subject was a very wide one, and the lecture to be given by Squadron Leader Blucke was confined to only a certain aspect of it—the actual approach to the aerodrome.

Introducing the lecturer, the Chairman said that Squadron Leader Blucke had been in the flying world for 20 years. He joined the Royal Flying Corps in 1918, saw service overseas, in India, and had since been in command of the Wireless Flight at Farnborough, where he had been particularly concerned in the experiments in the use of radio guidance under conditions of very low visibility. It was from one point of view sad to think that he had now been transferred to another sphere, but they must congratulate him on his new appointment to Bomber Command Headquarters at Uxbridge. That was the reward of success in one field—to be removed immediately far from it.

THE PRACTICAL USE OF RADIO AS A DIRECT AID TO THE LANDING APPROACH IN CONDITIONS OF LOW VISIBILITY.

By Squadron Leader R. S. BLUCKE, A.F.C.

1. FOREWORD.

The problem of landing an aeroplane under conditions of low visibility has been a subject for speculation for the last twenty years, but it is only within the last ten years that it has been given any serious practical attention. This practical attention has been forced by the necessity for aircraft to maintain schedule regardless of weather conditions in competition with other forms of transport.

Although certain schemes involving radio were amongst the earliest proposals for a solution of the problem, the first practical work appears to have been concerned with methods of a more mechanical or optical nature, including a proposal to deposit the fog by high tension discharge. In connection with these earlier attempts it would seem that investigators were chiefly concerned with the problem of actually touching the ground, and it does not seem that they fully appreciated the importance of taking up a correct line of approach from outside the vicinity of the aerodrome. This attempt to arrive at a solution of the absolute blind landing possibly militated against the earlier development of a system of landing aid which, though not perfect under the extreme condition will still be of the greatest assistance, and under the less extreme condition will certainly prove a practical solution to the problem. The problem of the final " touch down " would seem to be a matter for the aircraft designer.

The object of this lecture, however, is neither historical, technical nor prophetical of future developments, but is intended to describe two well known and well tried systems which simplify the problem provided the necessary radio equipment is available on the ground and in the aircraft.

" The practical use of radio as a *direct* aid to the landing approach in low visibility " has been selected as the title in order to differentiate between systems whereby a pilot receives radio bearings for his approach from the aerodrome control organisation and systems whereby a pilot, by operating a radio set under his own control, can receive signals either aurally and/or visually from transmitters situated on the ground in such positions that the indications received will enable him to find his own way into the aerodrome. He can thus dispense with assistance from the control organisation once he has obtained permission to land and received such routine details as local weather conditions and aerodrome barometric pressure for his altimeter correction.

This latter system will relieve the already overcrowded radio communication channel and enable the control organisation to concentrate their attention upon aircraft at a distance and those in the vicinity of the aerodrome awaiting their turn to land.

It is hoped that a pilot's impressions of the two systems during blind approach may be of interest.

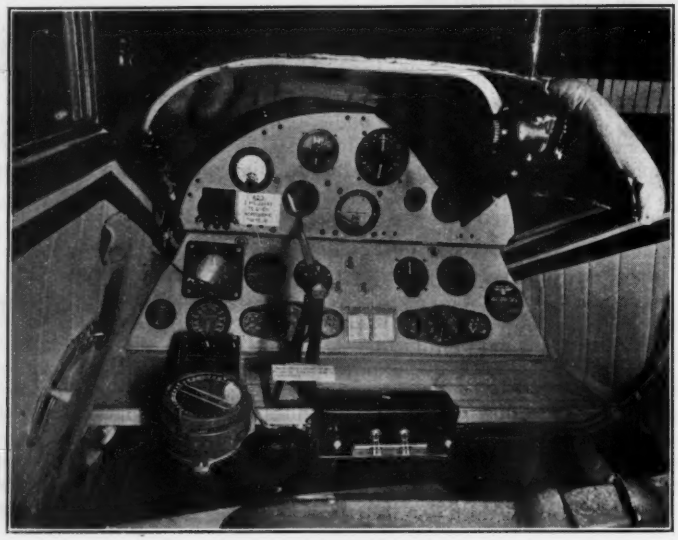


FIG. 1.

Aircraft instruments necessary for blind approach (Track Beacon System).

2. AIRCRAFT INSTRUMENTS.

Before considering the question of blind approach it is necessary to examine the aircraft instruments which will enable a pilot to control his aircraft in blind flight with the same degree of confidence, accuracy and precision as obtains when he is flying by normal vision. Blind approach is merely an advanced condition of blind flying and the ability to bring off a safe approach depends upon the pilot's degree of skill in flying by instruments, upon his power of concentration upon those instruments and his ability to interpret them, knowing

full well that he is nearing the ground and that in all probability he will not see it until the very last moment.

The instruments necessary to control an aeroplane about all its axes, when visibility is reduced to the distance of the instrument board, are those which convey to a pilot visual impressions which are of the same nature as the impressions prevailing in normal visual flight.

(Fig. 1)—In detail such instruments are as follows:—

An artificial horizon—for lateral and pitching movements.

A directional gyro—denoting the *amount* of yaw in a desired direction, and if synchronised with a magnetic compass, the orientation of the aircraft at any instant.

A sensitive altimeter—denoting height above a datum level which, for landing, will be aerodrome level (the correction scale in millibars enabling the aerodrome level barometric pressure to be set on the instrument before making the final approach).

An ascent and descent meter—denoting the rate of ascent and descent.

In addition to these, the normal flight instruments:—

An air speed indicator.
A magnetic compass.
A stop watch or clock.
An engine speed indicator.
A rate of turn indicator.

The rate of turn indicator has been placed last on the list of essential instruments because blind approach requires precise directional flying and a rate of turn indicator does not make for precision in direction, but merely marks a deviation from direction and the rate at which a turn is being made. This instrument is, however, of the greatest value when synchronising the directional gyro with the magnetic compass, and for ensuring that accurately rated turns may be made when so required.

Equipped with these instruments, an aeroplane can be controlled in any conditions of visibility and it only remains necessary to provide the pilot with some form of radio indications to enable him to follow his instruments along a predetermined track into the aerodrome, and so effect a landing.

3. Radio Indications Necessary for Blind Approach.

This predetermined radio track may be produced by one of two systems:—

(*a*) A track beacon system, or
(*b*) A radio compass system.

(*a*) Track Beacon System.

A radio beam may be laid down by a suitable transmitter on the ground on a predetermined track and equipment provided in the aeroplane so that by a pointer or listening to signals or both simultaneously the pilot is informed when the aircraft is on the centre line of the "beam."

It is to be noted that such a system gives no information as to the direction in which the aircraft is heading at any instant.

The aircraft is held along the track of the "beam" by means of the directional gyro, whilst the pilot is continuously informed whether his aircraft is following the track of the "beam" or wandering to one side or the other.

The Lorenz system is operated on this principle and, as is well known, a large number of aerodromes are equipped with this system, both on the Continent of Europe and elsewhere.

(*b*) Radio Compass System.

The aircraft may be equipped with a visual radio direction finder, usually termed a "radio compass," which indicates to the pilot by means of a pointer

instrument on the dashboard that the aeroplane is pointing towards the particular radio transmitter to which the radio compass is tuned. By using two such radio transmitters situated at each end of a predetermined track into the aerodrome and tuning the radio compass alternately to the one or the other, it is possible to follow this track into the aerodrome. This system was conceived and tested by Captain Hegenberger, of the United States Army Air Corps, and is understood to be in general use in America. The system bears his name.

In both systems the aeroplane must be given definite indication of its distance from the aerodrome, and this is usually achieved by the use of what are known as " marker beacons." These consist of small radio transmitters situated at appropriate distances from the aerodrome, usually one at about the edge of the aerodrome and the other some one and a half to two miles away, which emit a vertical sheet of radiation at right angles to the track laid down by either of the two approach methods. When the aircraft flies through the sheet of radiation emitted from these marker beacon transmitters a receiver in the aircraft is actuated and an appropriate lamp caused to light on the dashboard.

As regards vertical guidance it is possible to provide in the vertical plane a guiding " beam " on somewhat similar principles to that used in the approach " beam," and this may be caused to actuate a visual indicator on the dashboard so that the pilot, by keeping the pointer at a specified mark, may be assured he is flying down a definite path. On the other hand, the required information as to height may be given to the pilot by means of a sensitive altimeter, the aerodrome barometric pressure just prior to approaching having been transmitted to the aircraft by radio.

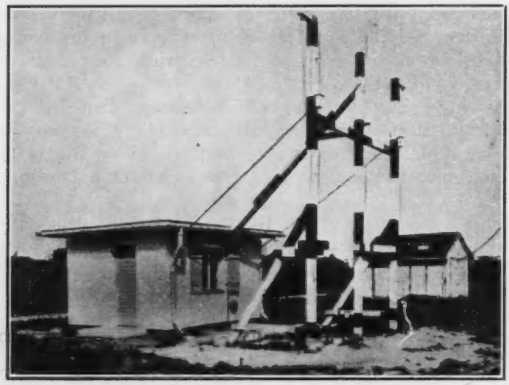


FIG. 2.
The Lorenz main beacon.

4. METHODS OF USE AND NOTES.

Both systems may be divided into three phases:—

Phase I.—The homing approach from a distance into the aerodrome approach line.

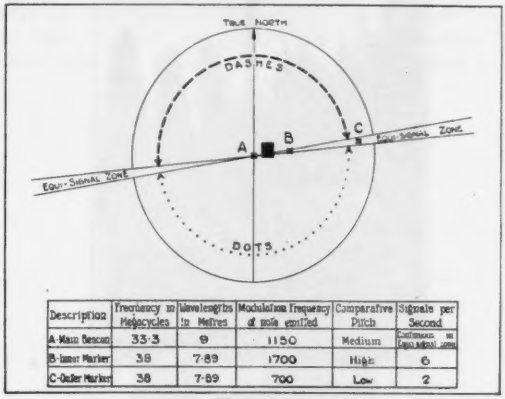
Phase II.—Taking up the landing approach line and reaching the aerodrome boundary.

Phase III.—Landing.

Note 1.—Before proceeding to describe each system it must be stated that the aircraft figures which are given hereafter are applicable only to the Monospar ST. 25 and these figures will necessarily require modification for other types of aircraft.

Note 2.—*In both systems it has been assumed that the pilot will not risk reducing height below* 2,000 *feet until he has actually reached the aerodrome and identified it.*

Note 3.—It must be pointed out that the flight manœuvres which may at first sight appear somewhat complicated, can be dispensed with *if* the pilot is quite certain of his position and distance from the aerodrome. *If* the pilot has no



Description	Frequency in Megacycles	Wavelength in Metres	Modulation Frequency of note emitted	Comparative Pitch	Signals per Second
A-Main Beacon	33·3	9	1150	Medium	Continuous in Equi-signal zone
B-Inner Marker	38	7·89	1700	High	6
C-Outer Marker	38	7·89	700	Low	2

FIG. 3.
The Lorenz equi-signal zone.

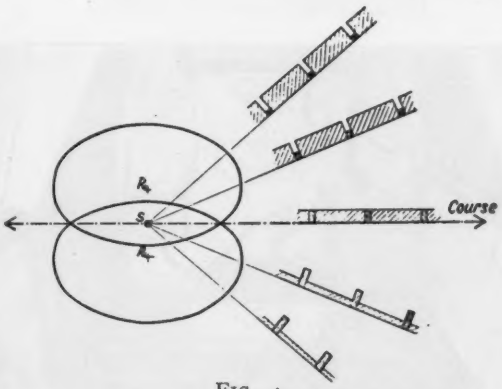


FIG. 4.
The equi-signal zone, dots and dashes produced by means of keyed reflectors.

knowledge of his position, then these manœuvres will enable him to adjust height without the needless risk of hitting obstructions or high ground before reaching the aerodrome.

What may be termed the " worst case " has therefore been selected for description.

Note 4.—As regards vertical guidance, the sensitive altimeter technique only is described in both systems.

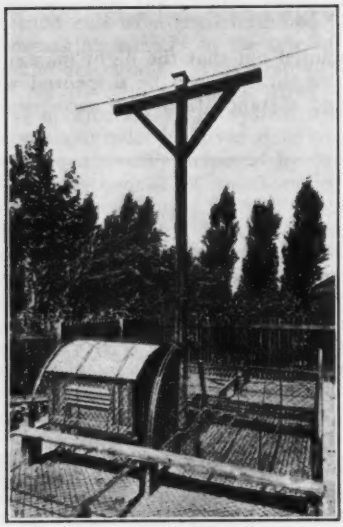


FIG. 5.
The Lorenz marker beacon.

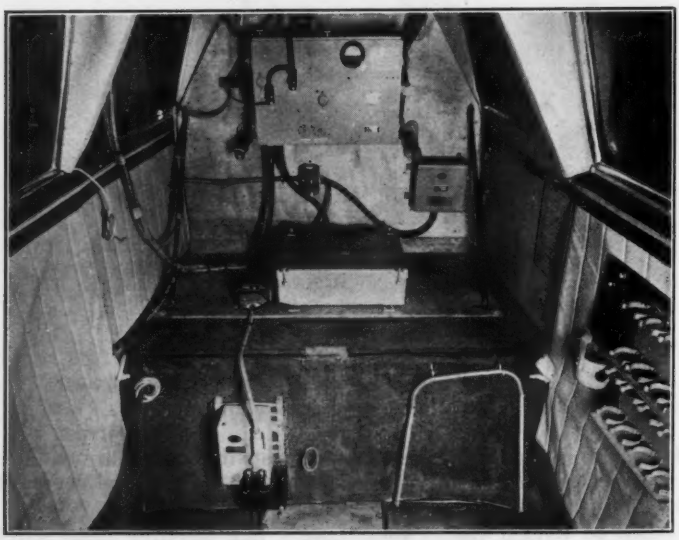


FIG. 6.
The Lorenz aircraft receivers.

5. THE LORENZ SYSTEM.

The Lorenz system comprises a main beacon with radiation through 360° in azimuth, and two marker beacons (Fig 2). The main beacon—a medium power transmitter on 9 metres—is situated on the extreme edge of the aerodrome and projects by means of reflectors an equi-signal zone about 4° in width (Fig. 3). This zone will hereafter be known as the " beam " for convenience. By suitable keying of the reflectors *dots* are produced in the left sector and *dashes* in the right sector (Fig. 4). Situated down the centre of the " beam " are the two low power 7-metre marker beacons, known as the " inner " and the " outer " (Fig. 5). These two beacons are spaced as follows:—The " inner " on the aerodrome boundary and the " outer " about one and a half to two miles away.

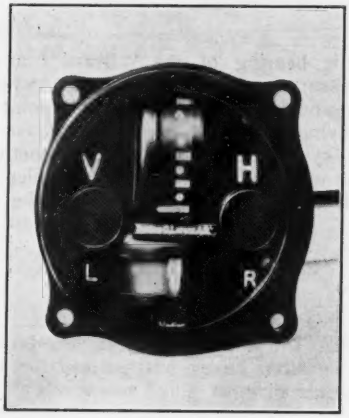


FIG. 7.
The Lorenz visual indicator.

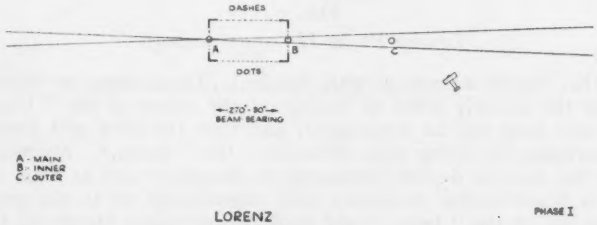


FIG. 8.
The Lorenz lay-out. Phase I.

The aeroplane is fitted with the necessary receiving apparatus which receives signals either aurally or visually from the main beacon and the marker beacons (Fig. 6). The bearing upon which the " beam " is centred must be previously ascertained by the pilot before contemplating a landing. When flying in the " beam " in the predetermined approach direction the pilot will receive a steady signal in his earphones; when the aeroplane is to the left of the " beam " the pilot will receive dots in his earphones and when to the right he will receive dashes.

On passing over the " outer " marker beacon he will receive signals of a low pitch at a rate of two signals per second superimposed upon the signals of the

main beacon, and on passing the " inner " marker beacon signals of a high pitch at a rate of six signals per second will be similarly heard. A remote control for switching the set and regulating aural volume is available for operation by the pilot.

In addition to the reception of aural signals a visual indicator is provided on the instrument board (Fig. 7). This comprises a moving pointer which kicks into the direction of the centre of the " beam " when the aeroplane is heading towards the main beacon in the predetermined approach direction and is stationary when the aeroplane is in the centre of the " beam," and two neon lamps each of which glows in unison with the sound when its appropriate marker beacon is flown over. In addition there is a vertical glide path indicator.

Two-way communication with the ground is necessary.

PHASE I (Fig. 8).

Ascertain the magnetic bearing of the " beam " at the distant aerodrome and the aerodrome pressure and adjust this to the sensitive altimeter. Set course for the distant aerodrome so as to reach a point about five miles down the " beam." Whilst flying this D.R. course care must be taken to ensure that the directional gyro is synchronised with the magnetic compass. Switch on the Lorenz receiver and when within about 20-30 miles of the aerodrome at a height of about 2,000 feet signals will be heard in the earphones. (Here it is

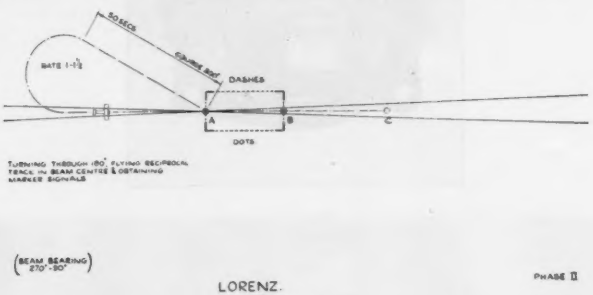


FIG. 9.

Lorenz Phase II (commencing).

mentioned that range increases with height.) These may be either dots or dashes or, in the unlikely event of hitting off the centre of the " beam " at the moment of switching on, an equi-signal, and thus the pilot will know in which sector the aeroplane is flying with relation to the " beam." Maintain a steady course until the dots or dashes commence to disappear and as soon as a steady equi-signal is heard in the earphones turn immediately on to the predetermined approach bearing of the " beam " and hold the aeroplane steady on this bearing on the directional gyro. By combining the gyro with the note in the headphones a course along the " beam " can be maintained. It is not advisable to pay any attention to the visual indicator until the centre of the " beam " is reached and the aeroplane headed down it. It is emphasised here that the directional gyro is essential for a steady approach; keeping in the centre of the " beam " may be done either visually or aurally according to taste, but a combination of the two is considered desirable. Approach the aerodrome at a safe height consistent with local terrain—say 2,000 feet. As soon as the " outer " is heard in the phones the pilot is immediately aware of his distance from the aerodrome and height may be lowered to 1,000 feet. During this approach any tendency to drift out of the equi-signal zone must be checked, and a suitable allowance for drift made on the directional gyro. (In fog there is normally little wind and consequently little drift.)

PHASE II (Fig. 9).

After passing the " inner " and on reaching the main beacon, which will be identified by a sharp cut-out in signals when immediately overhead, the aeroplane should be turned through 180° and flown back down the " beam " on the reciprocal bearing. The simplest way to make this turn is to add 30° to the " beam " bearing and fly on this course for 50 seconds at 100 m.p.h. followed by a rate 1-1½ to the left on the Reid and Sigrist turn indicator through 210°. On completion of the turn the aeroplane will be roughly in the centre of the " beam " and only small adjustments of bearing will be required to enable the

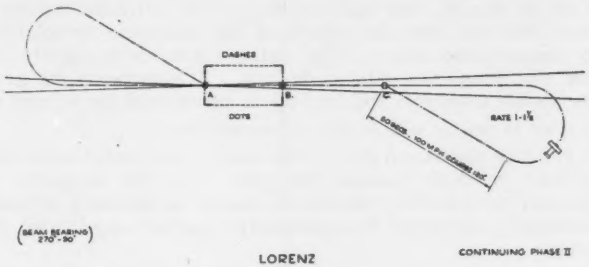


FIG. 10.

Lorenz Phase II (continuing).

aeroplane to regain the centre of the " beam." The " inner " marker beacon will now appear again and the pilot is aware of his position. It will be noted that in flying the reciprocal bearing the visual indicator works in the opposite direction to that which obtains when flying towards the main beacon in the predetermined approach direction.

(Fig. 10)—On reaching the " outer " turn at 30° to the reciprocal bearing fly for 50 seconds on this bearing at 100 m.p.h. Now turn through 210° at rate 1-1½ on the Reid and Sigrist and adjust the height to 600 feet, *i.e.*, in the case

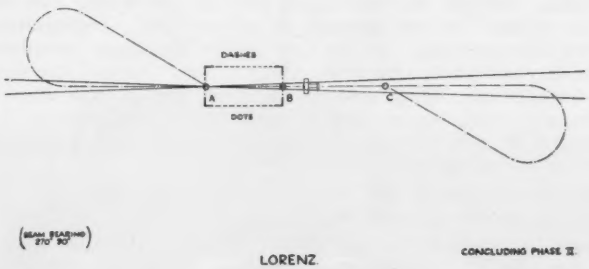


FIG. 11.

Lorenz Phase II (concluding).

of the Monospar 2,600 r.p.m., 100 m.p.h. A.S.I. On completing the turn the aeroplane will again be in the centre of the " beam." The correct gyro course must now be held, only slight adjustment being necessary according to the indications of the visual indicator or aural signals to bring the aeroplane back to the centre of the " beam." But it must be emphasised that as soon as the " beam " centre is reached the gyro is the master instrument to follow.

(Fig. 11)—Having obtained the " outer " marker beacon visual signal, wind back T.P.A. to the marked position on the wheel—throttle down to 2,200 r.p.m.—

adjust speed to 80—rate of descent 300 feet per minute—and keep in the centre of the " beam " by gyro and visual indicator aided by aural signals. Do not reduce height below 100 feet until aural signals from the " inner " marker beacon commence to be heard, and as soon as the " inner " marker beacon visual signal appears throttle back and commence Phase III.

PHASE III.

Hold a steady course on the gyro in the centre of the " beam," and ensure that the aeroplane is level laterally—A.S.I. 70 m.p.h.—rate of descent 300 feet per minute—and as soon as the sensitive altimeter registers 40 feet, speed should be adjusted to 65 m.p.h., the horizon bar of the artificial horizon should be brought gently into line with the wheels of the miniature aeroplane and r.p.m. increased to about 1,000 r.p.m. The extra r.p.m. will slightly increase the forward speed and lessen the rate of descent. At this point the ground should be sufficiently visible to enable the landing to be effected by normal vision.

There are several points which require emphasis :—

1. (Fig. 1)—The directional gyro is the master instrument when the " beam " has been reached. Check the gyro with the magnetic compass as frequently as possible, but do not make unnecessary alterations to the directional gyro unless it is obviously " out of step " with the magnetic compass.
2. Use the aural signals for approaching the " beam " and neglect the visual indicator until the centre of the " beam " has been reached and the aeroplane turned on to the directional gyro course towards the aerodrome. The amount of movement of the needle when off the " beam " is however some indication of the proximity to the " beam."
3. Visual signals from the marker beacons may not be seen above 1,000 feet, but aural signals will be heard up to much greater heights.
4. (Fig. 7)—The neon lamp of either the " outer " or the " inner " marker beacon glows only when the aeroplane is passing directly overhead. Aural signals can be heard before and after the visual indication. This is useful for height adjustments during the descent.
5. (Fig. 4)—The " beam " extends both sides of the main beacon and it is possible to reach the equi-signal zone on the wrong side due to faulty D.R. flying. In the absence of ground D.F. organisation this may prove disconcerting. In the case of the Monospar aeroplane, however, it is very noticeable that when flying in the " beam " the signal strength is much greater flying towards the main beacon than when flying away from the main beacon, and a 360° turn in the " beam " will readily indicate by reference to the directional gyro which side of the main beacon the aeroplane is flying.
6. Aural volume should be kept as low as possible. Too loud a note produces a singing in the head for many hours.
7. A correctly adjusted Lorenz system produces a clean steady note when in the " beam " and there is no mush. Consequently if there is any suspicion of dots or dashes the aeroplane is not in the " beam."
8. The twilight zone extends to about 20° either side of the equi-signal zone centre. That is to say, that the dots or dashes begin to be superimposed upon a steady signal as a background, the dots or dashes diminishing in strength, and finally disappearing, whilst the steady signal increases in tone and strength.

THE HEGENBERGER SYSTEM.

GROUND EQUIPMENT.

(Fig. 12)—This comprises two stations, either mobile or fixed, each consisting of a medium wave low power transmitter giving all-round radiation throughout

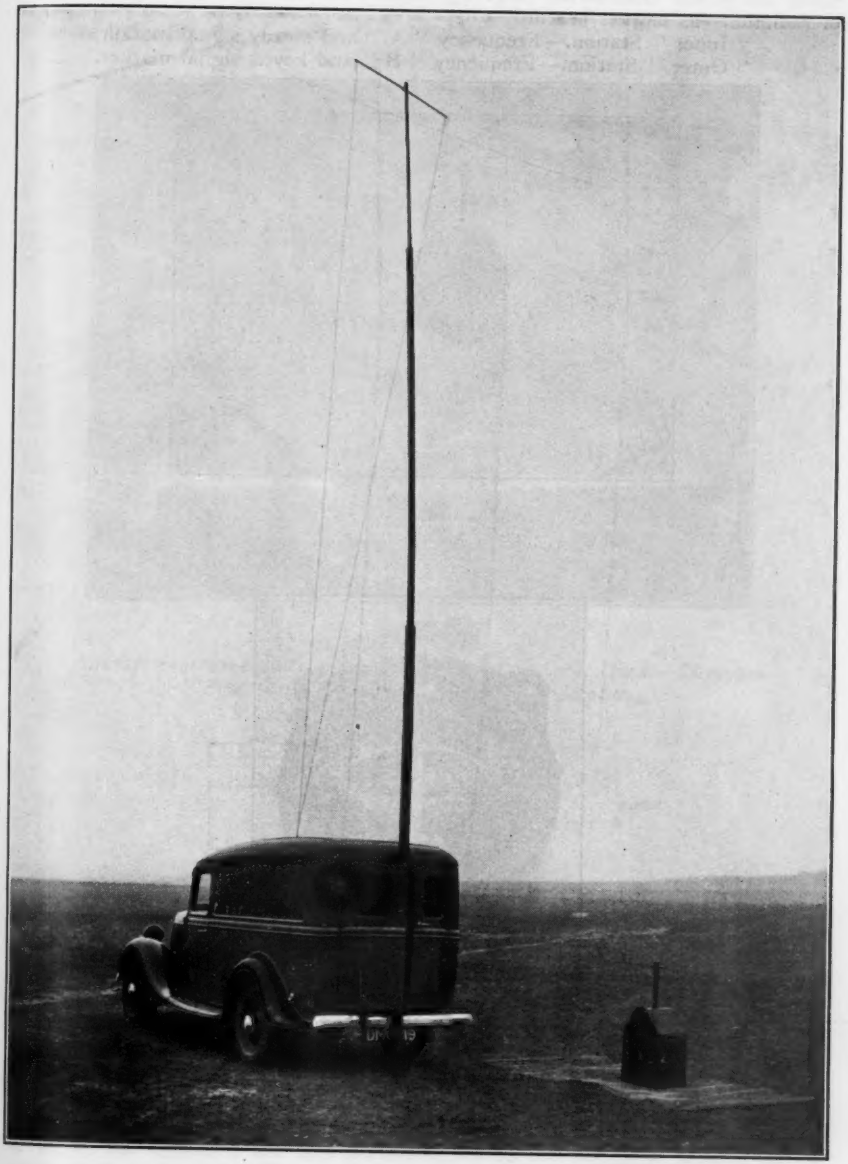


FIG. 12.
A mobile beacon station.

360° in azimuth for the radio compass in the aeroplane and each having a short wave low power transmitter (Fig. 13) capable of transmitting a vertical sheet of radiation—as marker beacons.

" Inner " Station.—Frequency " A " and steady signal marker.
" Outer " Station.—Frequency " B " and keyed signal marker.

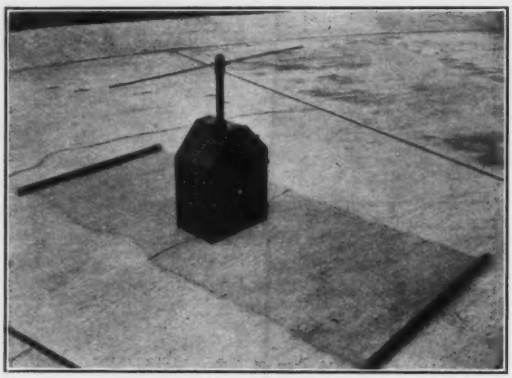


FIG. 13.
A marker beacon transmitter.

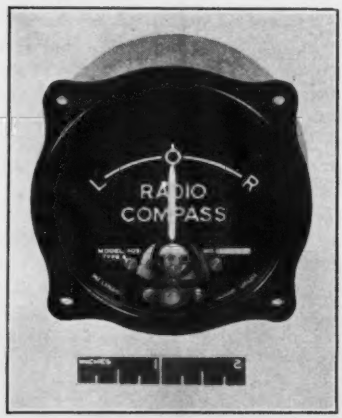


FIG. 14.
The radio compass indicator.

AIRCRAFT EQUIPMENT.

1. Radio compass receiver with remotely controlled tuning box within reach of the pilot.
2. Marker beacon receiver.
3. Radio compass indicator (Fig. 14).
4. Marker beacon indicator (Fig. 15).
5. Loop aerial and marker beacon aerial.
6. Distance or tuning meter.

PHASE I (Fig. 16).

Home on the " inner " from a distance at a safe height—say 2,000 feet—having previously ascertained bearing of approach line and aerodrome barometric pressure by radio.

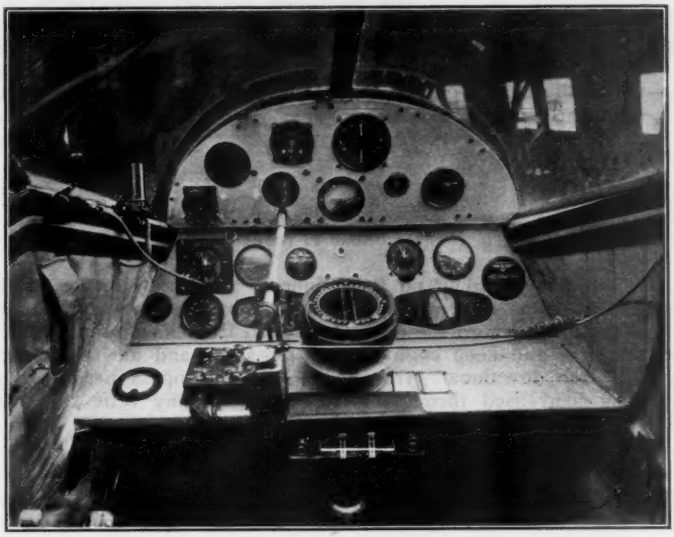


FIG. 15.

Aircraft instruments necessary for blind approach (Radio Compass System) showing marker beacon indicator.

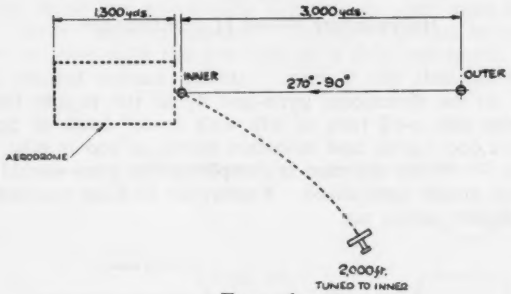


FIG. 16.

Hegenberger Phase I.

PHASE II (Fig. 17).

On reaching the " inner " and getting the marker signal turn on to a course at 30° to the approach line and preferably on to the magnetic bearing of the approach line plus 30°. This must be done very smartly and *immediately* the marker beacon appears. There is a tendency to lag in turning Now fly at 100 m.p.h., 2,900 r.p.m., for 50 seconds on this course, then turn at rate 1-1½ on Reid and Sigrist to left and 15-20° bank on Sperry horizon until a turn of 210° has been completed. Having completed the turn the radio compass needle

should be in the centre and if the turn has been made correctly the reciprocal bearing of the approach line will be showing on the gyro.

Keep direction now entirely on the radio compass needle which is still tuned to the " inner "—set the directional gyro on 180° and lock it. (This action also corrects for any possible precession in the gyro during Phase I.)

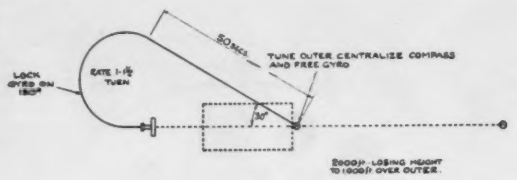

50 SECS
TUNE OUTER CENTRALIZE COMPASS AND FREE GYRO
LOCK GYRO ON 180°
RATE 1-1½ TURN
30°
8000' LOSING HEIGHT TO 1800' OVER OUTER.

FIG. 17.

Hegenberger Phase II (commencing).

Keep the aeroplane heading on the " inner " station by means of the radio compass needle and as soon as the " inner " marker comes up re-tune to the " outer " station and let go the directional gyro from its present 180°. Adjust height to 800 feet and keep engine r.p.m. at 2,900 and air speed 100 m.p.h. Note carefully the directional gyro and the radio compass needle. The latter must be kept centralised throughout this run and any drift that may have accumulated will be shown on the directional gyro.

FIG. 18.

Hegenberger Phase II (continuing).

(Fig. 18)—Immediately the " outer " station marker beacon light comes up turn on to 210° on the directional gyro and fly at 100 m.p.h. for 50 seconds at 2,900 r.p.m., then rate 1-1½ turn to left with 15-20° bank of Sperry horizon—throttle back to 2,600 r.p.m. and maintain speed at 100 m.p.h. Remain tuned in to the " outer." When the turn is completed the gyro should read zero with the radio compass needle centralised. Endeavour to have reached 600 feet when the " outer " marker comes up.

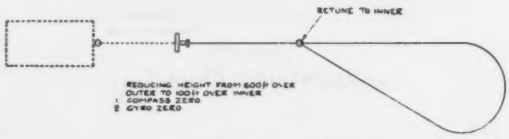


FIG. 19.

Hegenberger Phase II (concluding).

(Fig. 19)—As soon as the " outer " marker comes up re-tune to the " inner " immediately, centralise radio compass needle and note gyro. This should read zero with the radio compass needle central.

Wind back T.P.A. to marked position on wheel—throttle down to 2,200 r.p.m. and adjust speed to 80 m.p.h. In this position the top line of aeroplane of the Sperry artificial horizon will be halfway down the white bar of the horizon line, and a rate of descent of about 300 feet per minute on the meter. Keep the radio compass needle centralised and note the behaviour of the directional gyro—if no drift is accumulating this will remain on zero.

Note the distance meter and gauge how close to the " inner " one is approaching. A pilot will soon learn by experience the distances corresponding to any meter readings for a given transmitter.

Do not reduce height below 200 feet until the meter indicates a close approach to the beacon. Gain height by opening throttles slightly to about 2,400 r.p.m. if too low.

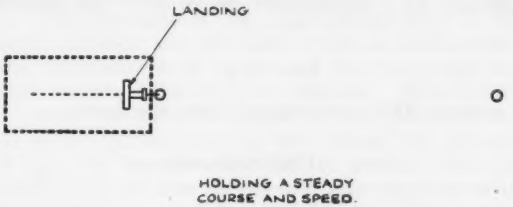


FIG. 20.

Hegenberger Phase III.

PHASE III (Fig. 20).

On reaching the " inner "—height should be 100 feet, A.S.I. 80 m.p.h., directional gyro 0, radio compass needle centralised. When marker signal appears, throttle right back and proceed with Phase III as previously described in the Lorenz system, the directional gyro reading 0 instead of the bearing of the approach line.

There are in this case also special points which need emphasis :—

1. (Fig. 17) Smart turning when over the beacon stations is essential. Swinging on to line and freeing the gyro on 180° must be done as soon as the " inner " marker appears. This point cannot be over emphasised. It must be done with the precision of a drill movement.

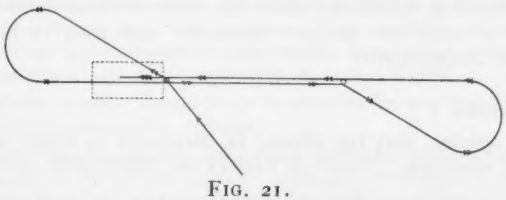


FIG. 21.

Diagram showing track of aircraft through Phases I, II and III.

2. (Fig. 21) If the line is doubtful after completing Phase I and Phase II and about to commence Phase III, the tendency to continue and " hope for the best " must be overcome, and the whole cycle repeated, even if it takes a considerable time.
3. If a repetition is necessary after reaching the " inner " marker on Phase II before commencing Phase III turn on to the 30° course from the approach line bearing and climb steadily on this course to 600 feet before recommencing Phase II

6. Pilot's Impressions of Two Systems.

Lorenz.

Advantages

1. (Fig. 3) Beam is set on a geographical line over the earth's surface and a pilot knows that if he follows this beam on the correct bearing he will reach the aerodrome.
2. Wandering out of the beam, a pilot is soon audibly warned that he has done so, and by correcting on his directional gyro is brought back again.
3. There is no anxiety regarding the receiver tuning which is fixed, only regulation of volume control being necessary.
4. Free from atmospheric interference.
5. Audible signals, *i.e.*, employment of hitherto unemployed sense in blind flight.

Disadvantages.

1. Need for external D.F. to " home " into the beam.

Hegenberger.

Advantages.

1. (Fig. 15) Pilot is immediately aware of the aircraft head in relation to the ground transmitter, by reference to the radio compass needle.
2. When approaching a beacon, right rudder produces right needle movement and vice-versa with left rudder, and consequently a pilot is immediately aware whether the ground transmitter is in front of or behind him.
3. Bearings for the initial " home " can be taken on any outside station, plotted and the D.R. course to follow found and held until within range of the local landing transmitters.

Disadvantages.

1. Radio compass receivers at present work on medium wave and consequently require medium wave transmitters on the ground. European æther is at present very congested and consequently the selection of suitable frequencies free from interference is very difficult.
2. Radio compass is rendered useless by interference and heavy atmospherics.
3. Pilot has to tune his receiver frequently and thus is burdened with an additional responsibility.

7. Fog Impressions.

I am of the opinion that fog should be measured in terms of vertical rather than horizontal visibility. There is usually an appreciable vertical visibility in fog.

Using the Lorenz system landings can be made with safety in a fog ceiling of 100 feet, always assuming that a pilot has an altimeter with which he is thoroughly acquainted, and which can be corrected in millibars given by a meteorological officer at the aerodrome of arrival.

I have made several landings with a cloud or fog ceiling at from 100 feet upwards and have experienced a sense of disappointment at seeing the ground from 100 feet, having received a good " inner " marker signal. A successful flight down the beam, getting correct marker signals and seeing the ground at even 100 feet instils a great degree of confidence and gives the feeling that if the ceiling had been only 50 feet one could have held on those few seconds longer before finally touching down.

(Under hooded conditions one does not get quite the same degree of satisfaction. One feels the whole time that the safety pilot is going to take over and slightly irritated when he does so.)

In this connection the Lorenz system, requiring, as it does, no attention on the part of the pilot other than the switching on of the set and an occasional reduction in volume of signal strength, creates a comforting sense of security under fog conditions. Once in the beam and on the correct bearing the pilot knows that the beam, being laid along a geographical line over the earth's surface will take him to the aerodrome, provided he remains on this bearing, and even if he gets off this bearing he will receive ample and urgent warning by sound and by sight.

The stable air conditions, which normally exist in conditions of *fog* with its freedom from bumps, seems to produce air which is more " solid " than it is on fog-free days. The instruments are consequently easy to follow—the aeroplane requires little attention and the pilot is left to concentrate his eyes upon height adjustment, maintenance of speed and direction, and his ears on main signals and marker signals when they are reached. There is a great sense of relief when the " outer " marker is reached for the first time.

I consider that in aeroplanes carrying two pilots, the second pilot or some other member of the crew should watch for the ground, thus allowing the first pilot full concentration on the instruments and relieving him of the necessity for glancing for the ground and so distracting his attention, as even momentary glances are sufficient to upset one's concentration. In the case of single pilot aeroplanes, of course, this cannot be done.

8. Conclusion.

In conclusion there are several factors governing a satisfactory blind approach which require examination from a pilot's point of view:—

(*a*) Training.
(*b*) Selection of the aerodrome landing runway.
(*c*) Aircraft characteristics in relation to the final touch down.
(*d*) Ice.

(*a*) *Training.*

(i) The well-known Link Trainer, which has been produced in America and is in use in this country, is considered of the greatest value for preliminary training in either system. This machine accustoms a pilot to interpreting his instruments and readily creates the necessary confidence to carry out a safe blind approach in actual flight.

(ii) Once trained, a pilot should keep in practice in any conditions of visibility as often as opportunity permits.

(iii) A pilot must be thoroughly conversant with the type of aeroplane in which he intends to carry out a blind approach and should preferably fly the same machine, as each aeroplane has individual peculiarities.

(*b*) *Selection of Aerodrome Landing Runway.*

(i) Runways should be at least 1,300 yards in length, the longer the better, and as level as possible. If a gradient is unavoidable, it is better to land uphill than downhill. At 1,300 yards the equi-signal zone is 86 yards in width. A runway width of 100 yards is therefore sufficient, but it should be remembered that after touching down there is a tendency to neglect the sound signals and swing off course a few degrees. This is possibly due to fatigue and sudden freedom from concentration coupled with relief at being on the ground.

(ii) There should be no flying obstructions on the approach line which will necessitate heights greater than the normal heights required to carry out a safe approach. There is a tendency to lose height rather quickly after passing the " outer " marker beacon and to reach the minimum permissible height over the " inner " marker beacon as soon as possible for fear of being too high and overshooting as soon as the " inner " is seen and heard. Consequently there should be no flying obstructions greater than the minimum safe height over the " inner " marker beacon for at least half a mile before reaching the " inner " marker site.

(iii) The blind approach line should not be placed on a due north or due south bearing if this can be avoided, since a directional gyro is governed by a magnetic compass which is subject to northerly turning error. Although the directional gyro is the " master " instrument during the approach it is essential to place the magnetic bearing of the equi-signal zone on the compass and so ensure that the compass and gyro are synchronised throughout the approach. Such synchronisation is almost impossible on a north or south course. A pilot should remember that acceleration error is noticeable on westerly and easterly courses and should maintain a steady speed and attitude when synchronising.

(iv) The control organisation should be in close touch with the W./T. Office and Meteorological Office so that the barometric pressure at aerodrome level can be given without delay to an incoming aeroplane. Such information is essential to the pilot and he must not be given any grounds for doubting the accuracy of the corrections in millibars given to him.

(v) A chalk line should be provided down the centre of the equi-signal zone suitably marked in distances as at Croydon and elsewhere. Lights should be sunk into the chalk line and if possible the edges of the beam suitably illuminated for night landings.

(vi) All transmitters should be under the control organisation and suitable apparatus provided to indicate to the control that all transmitters are functioning correctly.

(*c*) *Aircraft Characteristics in Relation to the Final Touch Down.*

The ability to bring off a blind touch down seems to be a matter for the aircraft designer.

The three-wheeled undercarriage fitted to an aeroplane longitudinally stable, with suitable leading edge slots and suitable flaps to vary the glide characteristic at will, should solve the problem. An aeroplane with a three-wheeled undercarriage requires no hold-off or flatten out, and, in fact, presents no " landing problem."

(*d*) *Ice.*

Finally, low visibility probably means fog and fog probably means ice, and to enable a pilot to fly his aeroplane with the maximum of safety and with the minimum of anxiety under such conditions it is necessary to guard his aeroplane from ice and to ensure that all flying and radio instruments will function under the worst atmospheric condition.

The author wishes to thank Standard Telephones and Cables, Limited, for their kindness in lending certain photographs illustrating the Lorenz system.

Discussion.

The Chairman: He was sure that all present would wish him to congratulate Squadron Leader Blucke very heartily upon an excellent lecture of great interest to them. As so many of them would be anxious to join in the discussion, he hoped that those who took part would try to confine their remarks to the actual

operation of blind flying systems. It would have been interesting, of course, to hear about many details of the instruments required, but with the limited time available, he felt that that would mean throwing the discussion open too wide.

Wing Commander DE BURGH (*Associate Fellow*) : In complimenting Squadron Leader Blucke on his extremely interesting lecture, he wished also to pay a tribute to the flying work which the lecturer had done in connection with those experiments. From what Squadron Leader Blucke had told them, they might be under the impression that he had two ready made systems brought to him, and that he simply went up and tried them. That was not the case. There was a lot of experimental work to be done in actual flight, and one could imagine few things less pleasant than flying in very low visibility to test blind flying equipment in the experimental stage, but Squadron Leader Blucke did it most admirably. A tribute was also due to Mr. Cox Walker, who had been dealing with the technical part of the problems involved. If there was anything less pleasant than flying a machine in low visibility, it was to be found in being a passenger under such conditions.

Taking one aspect only of blind flying, Wing Commander de Burgh said he would like to speak on the question of vertical guidance. The lecturer had not said much about it. But the habits of vertical guidance had been observed, and it was because the habits of vertical guidance from a radio point of view were not very reliable that he (the speaker) wished to lay stress on that fact. In the diagrams commonly published in various periodicals and papers was to be seen a prettily shaped lozenge of radiation down which an aeroplane flew with perfect ease. That was theoretical and not practical. In point of fact, that lozenge was liable to be distorted, because there were objects in close proximity with the transmitting aerials which affected the shape of the lozenge. If only the earth could be removed completely away from the transmitting aerial, they would get a perfect lozenge shape. The distortion was worst in the case of vertical aerials, but could be improved in the case of horizontal aerials, but, even so, the earth was in close proximity and it was liable to have ill effects on vertical guidance; and these ill effects were not constant because they were dependent on the conductivity of the earth, which was variable.

He was convinced that the one essential of any system connected with blind landing must be complete and absolute reliability. Certain claims for vertical guidance had been made in print, and he had no doubt that the system would be perfected in due time, but it must be considered as being in the experimental stage at the present moment.

Mr. RODERICK DENMAN (*Fellow*) : He was afraid he was not in a position to say much about the operation of the Lorenz system at Heston, because it had not been used extensively. He believed it was true to say that for over a year there were more blind landing beacons in England than there were aircraft equipped to use them.

The lecture had been most admirable and did full justice to its title, in which the emphasis was on the word " practical." After so much talk about blind landing, it was gratifying that, at last, some useful action had been taken in this country.

If he might say a word, not exactly of criticism, but in comment, it appeared from the lecture that Squadron Leaker Blucke considered that the Lorenz and Hegenberger systems were comparable in performance. That was not the impression which he (Mr. Denman) received when he visited America four years ago for the express purpose of making a study of the various systems. The impression which he got then—borne out by practical demonstrations which he saw at Langley Field—was that the Hegenberger system could not compete with the track beacon system so far as the needs of air line companies were concerned. It was pointed out to him—and he would pass it on to the meeting—that whereas the track beacon system incorporating a vertical " glide path " did contain

potentially the means of bringing off a completely blind landing, the Hegenberger system did not. If, for the sake of example, it were assumed that in 90 per cent. of cases the Hegenberger system would bring a man down in conditions of nil visibility there was no indication given in the other 10 per cent. of cases as to what had gone wrong; consequently, systems like the Hegenberger could not, in his view, be regarded as blind landing systems at all. At best they were blind bumping systems, in which the machine came down and the pilot hoped that it would hit the ground with as little force as possible.

When he was in America he made contact with many persons who had practical experience of the original blind landing beam of Diamond and Dunmore. It was the opinion of those who had tried it that the vertical guidance was sufficiently accurate to be of real value in this and future landing systems.

He quoted from a report made to Transcontinental and Western Air, Inc., the following:—

"There is a slight raising of the landing beam in wet weather. A snow blanketed field has a similar effect on this beam but to a lesser extent. In no case is the change great enough seriously to affect the approach on landing. The landing path is made steeper at some distance out, but the change makes very little difference over the edge of the field, the lines of equal signal strength in the landing beam being very close together at this point."

The tenor of all the criticism that he heard was that Diamond and Dunmore had pointed the way to a satisfactory solution of the blind landing problem and that their work had been deliberately set aside in favour of the Hegenberger system. This was pre-eminently a military development and had never been used by any of the American air lines.

He did not underestimate the value of the track beacon systems that were being used in Europe at the present time. They were practical. They were indeed the only systems that Europe had produced. But it would be a pity not to recognise that in America opinion in regard to the Diamond and Dunmore system had been practically unanimous.

(*Communicated.*) Why does European opinion, so markedly different from that of America, insist that the landing beam or glide path is unreliable? He thought the explanation would be clear after reading the following two paragraphs. They are taken from a letter which describes the successful demonstration of a new blind landing system, designed to comply with specifications drawn up in conference by the Radio Technical Committee for Aeronautics (sub-committee on instrument landing), the Bureau of Air Commerce, the Federal Communications Commission and all the major United States air lines. The italics are the writer's:

"In the practical demonstration 20 or 30 pilots (Army, Navy and air line) flew the system and made actual perfect landings, all confined to within approximately a 200-foot circle. *Horizontal polarisation of the glide path is essential to accurate indications close to the ground.* An experienced pilot needs only about one hour practice and instruction before being able to make perfect hooded landings."

"Our test of the Lorenz Instrument Landing system indicated to us that the frequency on which it operated was not high enough and the vertical polarisation of the glide path gave unreliable indications close to the ground. *This was proved to our satisfaction by changing the equipment to give horizontal polarisation.*"

He repeated his former assertions that positive vertical guidance is both feasible and highly desirable in a landing system.

Mr. C. E. G. Bailey (Radio Transmission Equipment Limited): It would be extremely desirable that civil air lines who were intending or who were about to use equivalent apparatus should get into touch with the lecturer in order to maintain the maximum co-operation with him, or his successors, if any, to enable them to find out the equivalent figures for their aircraft as to attitude, air-speed, rate of turn, etc., as had been found out for the Monospar S.T.25.

In relation with the two types of system which had been under discussion, there might be certain interesting features about a third available type which was not altogether outside the purview of the discussion, because it combined some features of the medium wave beacon and the ultra short wave beacon. He was referring to a type of medium wave beacon of which there had been a specimen on the Continent at Schiphol and of which Radio Transmission Equipment were supplying three to the government of New Zealand. In this beacon medium waves were used, but there was a track provided by the interlocking of dots and dashes in an equi-signal zone. It was of the same nature as the ultra short wave system. It had this advantage that a homing indicator or radio compass could be used on the beam. The pilot might use the radio compass instead of the gyroscopic compass as a means of establishing orientation of the aircraft head to the aerodrome, and therefore he had no need of special cognisance of the path of the beam, and in addition the radio compass was a somewhat more quickly acting instrument. Then he could use the dots and dashes as a means of establishing his lateral deviation from the course and a single frequency only need be used. To avoid the necessity of re-tuning the receiver, marker beacons were used on about the same frequency as the main beacon.

That introduced problems of accurate synchronisation of two frequencies, and in order to keep the marker beacons simple and compact the marker beacons were frequency-modulated at about the frequency of the main beacon. That was to say, their frequency was fairly slowly varied in a rhythmic manner, which produced a beat tone of slowly varying frequency.

Through the courtesy of Mr. Denman, he had been able to prepare a gramophone record which would indicate, first, that these sounds were absolutely recognisable and showed the difference between the inner and outer marker, and, secondly, they did bear some resemblance to the marker signals of the ultra short wave system, so that the pilot would not be subject to any confusion of mind.

(Mr. Bailey demonstrated with the gramophone record.)

Mr. L. A. Sweny: He was interested in the remarks of Wing Commander de Burgh on the glide path. To a certain extent they bore out the early experience of the Marconi Company some years ago with the commercial beam system, when it was found that the lozenge shaped radiation to which the Wing Commander referred did, in fact, alter quite considerably with the varying conditions of ground conductivity.

There was one question which he would like to ask Squadron Leader Blucke. He had shown them diagrams of what he (the speaker) thought was a rather complicated approach. Was it not possible for that to be simplified down to an ordinary approach straight to the equi-signal zone, making one flight down the laid-down approach path, instead of flying over the aerodrome and then making a 30 degrees turn and flying back over the aerodrome before commencing a landing? He thought the technique at present used by the air lines flying into Croydon was to get on to the laid-down approach by the aid of direction finding on a medium wave and then to adjust the height of the aircraft whilst flying between the two marker beacons, so that when over the inner marker it was possible to make a normal landing in even bad visibility. Perhaps, however, that should not be done by a pilot until he had had considerable practice at aerodromes at which he was used to landing daily.

Captain F. Dismore (Imperial Airways): The main point which he noticed was that the experiments seemed to have been carried out principally in the calm or normal conditions which existed in fog. But the biggest difficulty which pilots in the Imperial Airways had was in coping with the Lorenz and other types of blind landing under conditions when there was wind to contend with. That was particularly noticeable on large aircraft where the keel surface was such that the pilot had a difficult job to hold the machine on any particular track, particularly when his approach line was restricted. He did not know whether Squadron Leader

Blucke had had any experiences in that connection; but that seemed to be the biggest trouble. Approaches did not give them any particular difficulty in picking up the beam or markers but actually holding on the track, particularly where the limits were small, as at Croydon for instance, which is found to be abnormally difficult.

Mr. F. S. BARTON: It had been his duty on behalf of the Air Ministry to go about and investigate and see demonstrations of radio aids. Through the courtesy of various air lines and administrations, he had seen a good many radio demonstrations and finally had the complete Hegenberger system demonstrated to him in America. He was allowed also to take part as a passenger in a completely hooded approach and landing.

When the Air Ministry decided to do experiments the Hegenberger equipment was not commercially available, so an existing radio compass was used and the marker beacon and ground equipment designed and made at R.A.E. Squadron Leader Blucke and Mr. Cox Walker deserved all the compliments which those present and others had paid to them for they used the Hegenberger system without any previous demonstrations of it.

He thought that Squadron Leader Blucke was just a little hard on the Hegenberger system. He was not going to discuss radio compass systems and track systems with Mr. Denman. They had both seen them and arrived at different conclusions. One advantage about the Hegenberger was that of mobility.

The lecturer had mentioned the disadvantage of the pilot having to fiddle about with tuning the radio receiver. That difficulty had been already foreseen; there had been proposals by Hegenberger himself and others to overcome this. He thought also there was a Siemens patent which specifically referred to the use of a radio compass for defining an approach line by means of two fixed ground transmitters.

It was quite true that the congestion of the ether in the medium wave band by broadcasting stations was another disadvantage. Radio was the only means by which aircraft could be communicated with and helped from a navigational point of view while entertainment and news could be delivered to the public over telephone or electric supply systems. In America, a whole band of wave lengths had been set aside for radio aids to air navigation. In Europe broadcasting had taken up wave lengths for entertainment and advertising purposes simply because navigation had not sufficient public opinion behind it to get allocations of wave lengths at the international conferences. People ought to appreciate the fact that when they were listening in to Luxembourg, Droitwich, Radio Paris, etc., they were encouraging the use of wave lengths for entertainment and propaganda that ought to be used for the safety of civil aircraft. He hoped that in the future public opinion might be roused to the essential importance of radio for civil aviation, so that frequency allocations for these services involving safety of life might have a prior claim over entertainment and propaganda as represented by broadcasting.

Squadron Leader NIGEL NORMAN (*Fellow*): He would like to ask one or two questions connected with the practical operational side of the subject. Squadron Leader Blucke, to whom he paid his tribute of thanks for his work, had suggested that from the zoning point of view there should be no obstructions within half a mile of the aerodrome and that there should be minimum safe height over the inner marker beacon. This requirement would certainly greatly complicate the question of selection of sites and would involve the interests of individuals owning the land. He was afraid that it would, in many cases, be difficult to achieve in practice.

Regarding the operation of the system, the lecturer had stated in great detail the very interesting method evolved for making a correct approach, but it seemed to him (the speaker) that it had two disadvantages from the point of view of civil air transport. One was that it covered a considerable amount of country

apart from the track of approach, on which there might be other aircraft. The other was that it might involve a considerable amount of time. One of the difficulties of the future would be that schedules of aircraft arranged with regard to normal visibility would have to be carried on in bad visibility, and the allotting of 10 or 15 minutes to every landing would complicate the schedules enormously, but however difficult it was they must arrive at a system in which an aeroplane could make a direct approach, flying straight into the beam, and complete the landing without any circling of the airport.

He suggested that some problems could be simplified by providing more than one outer marker beacon. He had never understood why there was only one. The beacons did not cost much. Why did they not have three or four outer marker beacons, if necessary, to give the pilot an absolutely definite track before the final run in?

In his reference to lighting, the lecturer had made it clear that there should be a line of marker lights along the centre of the blind landing run and that the edges of the beam should be marked by flush marker lights. He had hoped to bring a lantern slide to that meeting showing such an arrangement on a scale model, but it was not ready in time. He asked the lecturer how wide should be the track which would be delimited by additional lights. It seemed clear that the lecturer was in favour of three lines of lights, but the practical problem arose as to how they should be located. The lecturer did not make any reference to the question of threshold at the beginning or end of the runway. Did he think a clearly marked illuminated threshold would be a valuable addition?

Was it not really a fact that on any large transport aerodrome there should be more than one direction of radio-guided landing? The system was admittedly one for blind approach, and the question of completing the blind landing was not really dealt with in the paper. Blind approach might be necessary in various conditions, for instance in snow, heavy rain, low cloud ceiling and other conditions, and he asked the lecturer if he felt, as he (the speaker) felt that in any properly equipped large terminal they must have at least systems of radio beam inclined approximately at right angles to each other.

No mention had been made of the automatic landing, which seemed to represent the development of this science which was now engaging the attention of American experts who were apparently in this respect little ahead of us in practical research, not for any reason other than that our research organisations in this country were starved of money. Automatic blind landing had not been referred to.

Mr. A. HITCHCOCK: What had struck him most had been the absolute change in the views of the pilots in the operating lines. In the first place, there had been bias against the use of a system of that kind. The average pilot, particularly in bad weather, might have had a reputation to lose by having a system that would help him to get in, but recently a change had taken place. In the air line with which the speaker was connected (British Airways), they had nine machines fitted with the Lorenz system and the pilots would not leave the ground until it was certified as working, particularly on night flying. They might use it as many as six times in a journey. On the Cologne, Hanover and Berlin route they often used it five times in 36 hours.

Recently one of their young pilots brought in a machine in filthy weather without any time to circle round the aerodrome and in very bad visibility he made a perfect landing. As pilots got used to the Lorenz, he was sure they would definitely not leave the aerodrome without it.

Squadron Leader BONHAM CARTER, invited by the Chairman to say a word as to the effect of high loading on blind landing, replied there was very little that he could say that Squadron Leader Blucke did not know himself. The lecturer had had experience of all the latest types of aircraft. There were certain characteristics of the newer aircraft which were not, perhaps, present in the aircraft to which most pilots had been accustomed and were certainly not present in

the Monospar, which perhaps was selected because it was suitable for those experiments in view of its satisfactory controls and easy flying properties.

There was perhaps a tendency in the designers of modern service aircraft to find it difficult to provide sufficient lateral stability. He did not know whether it was inherent in the monoplane design with a folding undercarriage, but in a good many modern types there was only just sufficient lateral stability. The pilot doing a blind approach had enough to look at without worrying whether he was laterally level at the time, and he might welcome a little more stability in that direction.

While the designer found it difficult to provide lateral stability, he found no difficulty at all in providing directional stability. Some of our modern aircraft were so stable directionally that it was hard to make them go in any direction at all other than straight ahead. (Laughter.) Did the lecturer think that there would be trouble resulting from this—he would not say it was a vice, because in certain conditions it was a good quality? If it was thought that a pilot could keep on his beam by giving an occasional push to his rudder-bar, experience might prove otherwise. The speaker thought that with the increased speed ranges which they had now there was a tendency for aircraft to be a little less manœuvrable at low speeds in their landing approach, when the flaps were correctly set and the undercarriage was down for landing. The effect was to make the pilot more committed to his landing than in the past.

If the undercarriage was down the drag was considerable. That business of flying round near the ground in fog in landing rig might not be pleasant. Pilots might find they could not use the same setting of flaps that they used in conditions of normal visibility, because they had to be ready to increase their height if they went round again and did what the lecturer called "a smart turn." With this reduced flap setting his aeroplane might have too flat an approach or might not lose speed quickly enough when near to the ground.

As regarded actual landing characteristics, he thought that most of the modern aircraft were easier to land, partly because they had a flatter angle on the ground, so that it was almost possible to fly them straight on to the ground without very much effort to flatten them out; also because they had nice spongy undercarriages with wheels spread well apart. Their landing characteristics should therefore simplify the making of contact with the ground in fog.

Mr. W. O. Manning (*Fellow*): Had there been any experience with blind landing systems over water and, if so, with what results?

Captain J. M. Furnival (*Associate Fellow*): He had two or three questions to put as a seeker of information from the point of view of aiding development work in regard to landing aids.

The lecturer had mentioned a track width of 86 yards at a distance of 1,300 yards from the main transmitter. It seemed there was a tendency, if the track width was at all wide, to cling to the edge of it, so that the predominating signals, either dots or dashes, were just beginning to emerge from the even signal. This might well have the effect of increasing the width of the track. He would like to know whether the lecturer would agree with him on that point and what he considered the ideal width of the track should be.

They had been experimenting for some time past at the Croydon Aerodrome on an equi-signal system, in which there were two overlapping beams. By providing more or less concentration of the beam, it was possible fairly readily, by the design of the aerial system, to provide a track, within reason, to suit any particular requirements.

The twilight zones mentioned by the lecturer were to some extent under similar control. Actually in the experiments at Croydon they found a track width of about 40 yards was quite suitable at approximately the same distance, and, if one sharpened up the discrimination in that way, it appeared to have the effect of improving the accuracy of the indications, and consequently the steering.

His next point was that if one had a beam system, such as he had described, the ambiguity of meeting the equi-signal beam on the wrong side of the station was to a large extent avoided, because the beam energy was concentrated in a forward direction in a ratio of about 9:1 of radiated energy. It produced a major beam or track forward and a minor one at the back, and the differentiation between the two was fairly definitely marked.

There was another advantage, viz., that beacons could be placed closer together without mutual interference, thus avoiding the complications of wavechanging to a receiver which was otherwise simple and straightforward to operate.

Following upon a remark by a previous speaker, he would much like to know what the lecturer thought about the possibility of applying to the system the aid of the automatic pilot. In earlier work, done in the summer of last year, in connection with the coupling of the radio compass to the automatic pilot, it was quite evident that one could obtain an accurate system of steering simply because of the time factor involved—one got instant response—and, as accuracy of steering was important in approach work, there would be a useful field of development in that direction. On the other hand, the diagrams shown in the lecture seemed to indicate that one required also a fair degree of manœuvrability. Consequently, he should like to ask the lecturer whether he had any views on the application of the automatic pilot, either to control the orientation of the head of the aeroplane by the signals from the radio compass being applied to it or by application of track signals direct.

They had tried both schemes at Croydon and both seemed to be feasible. They also thought that the application of the radio compass superimposed on the nine-meter signals would give many of the advantages of the Hegenberger and Lorenz systems combined in one. For instance, a machine fitted with radio compass could perhaps take its bearings from one or more of the existing long wave broadcasting stations, which they at Croydon had used and found to be very reliable and useful.

Mr. W. E. Gray: His main impression was that the whole process seemed to be very complicated, after years of study, and he suggested that the subject might be furthered if the Society held an informal discussion on all the possible methods of blind flying and landing.

Reply to the Discussion.

The reason he had not said much about the glide path was that he had very little faith in it in its present condition. He had tested the glide path on, he thought, 15 aerodrome sites in England, but it never seemed to do the same thing twice. He had had instances where the glide path needle had brought him down to below 50 feet, half-a-mile from inner marker beacon; instances where the glide path needle indicated that he was too low when at an actual height of 50 feet between the inner and the main; and other instances where the glide path needle had indicated safe heights from outer to touch-downs; with such experiences of the glide path he did not feel that he was in a position to say much in favour of it. At the moment, his experience suggested that in its present form it was not worth its place on the meter. The path indicated by the "glide path" did not conform to the glide characteristics of normal aircraft.

Mr. Denman had asked whether he preferred the track beacon or the radio compass system. He (the speaker) personally preferred the track beacon system. The reason was that the beam was definitely laid along a geographical line into the aerodrome, and as long as one stayed in the equi-signal zone one knew quite well that one would reach the aerodrome. Now, with the radio compass system, one had to make one's own beam, and had quite a lot of things to do to make it.

That led him on to a point which several speakers had raised about that "complicated figure of 8." He quite agreed, it did seem complicated at first sight, but he thought that they had missed his point which was that the pilot had no radio aids, other than the Lorenz gear, to let him know his position. By doing

the " complicated figure of 8," the aerodrome could be found, identified and height adjustments made for landing. In doing their tests, at the R.A.E., of a 30-mile cross-country from A to B, under the hood, and in fog conditions, they had had no radio other than the Lorenz equipment, they were above high ground across the Chilterns, and he personally preferred to keep up and get in without bumping the Chilterns. But he agreed with several speakers that if one knew where one was one would not " prolong the agony," but in cases where one did not know his position then this system had been evolved and it worked very satisfactorily.

With regard to Captain Dismore's point about heavy machines, he (the speaker) had no experience of types other than the Monospar. If an aircraft could be landed by vision and could be flown satisfactorily on instruments, he did not see why the approach could not be made by instruments on any type of machine, provided, of course, the pilot was thoroughly conversant with the type. It was a snag, he agreed, that the Lorenz system was not always into wind, but if the wind was so great that one must land into it surely there would be sufficient visibility to make a normal landing. He always felt that wind speed and visibility were very closely related, except in the case of a snowstorm and a gale at the same time. If such happened, with the track beacon system, one could always do a crash landing in the middle of the aerodrome, which was better than hitting someone's house in the vicinity.

The question of handling heavy machines had been raised by Squadron Leader Bonham Carter, and he (the speaker) thought it remained to be seen. If they could be landed by vision, then he thought they could be landed down a track beacon. He was prepared to try and see. He thought it was pretty hopeful; after all, a large number of different types had already been fitted in the commercial sphere and had been used successfully. He thought it was up to the aircraft designer to design aircraft with satisfactory handling qualities, it was no good making aeroplanes which would only fly straight and had poor directional and lateral stability.

Mr. Nigel Norman had raised the point that civil air transport machines did not want to waste time coming in to land. He thought that all transport aircraft were obliged to be equipped with D.F., and if the pilot knew his position and could get an accurate fix from the ground there was no need to turn and twist round the aerodrome; he could go straight in. The beam, however, did not always happen to be straight ahead and one might strike the beam close to the aerodrome, and at almost right angles in which case turns were necessary. Coming in from the Continent to Croydon, one had to come down the back beam. If one got into the back beam and waited for the appropriate marker and main signal at a reasonable height of 1,000 feet, and then executed that method of turning it would enable one to turn and fly down the beam to land. This method of turning was not just a hit or miss method, as it rather appeared. There were three essentials connected with it. A constant speed must be maintained the whole way round the turn. The two things closely related were:—The time of flying and the rate at which the turn was made. Allowing for the human error and the local variation in wind, etc., if one took a base line of 50 seconds and turned at a rate of 1 to 1½—*i.e.*, not less than 1 and not more than 1½—one would just complete 210 degrees by the time one had regained the centre of the beam. It was very noticeable that if one got careless in turning and did not fly for 50 seconds or flew at a rate 2 or rate 3 he would miss the beam centre and possibly the outer marker.

With regard to the question of supplying an extra marker, he thought that that was a very sound idea, and should be carried out whenever possible. He appreciated the difficulty of attaining his ideal of having no obstruction for half-a-mile from the inner marker, thus enabling a constant minimum safe height over the inner, but he thought this was an ideal at which to aim.

He personally was not in favour of threshold illumination. He thought a pilot should remain on his instruments right down to getting the inner signals. It was very disconcerting to come off the clocks and glance out before getting an inner signal. He would advocate staying on the instruments right down to the inner and then glancing for the ground. Threshold lights before the inner might be useful, for it is impossible to have too much in the way of aids to landing in bad visibility, but he did not want any illumination before the inner signal to distract a pilot's attention from his instruments until he had received his inner marker signal.

He was very interested to hear from Mr. Hitchcock of the number of machines being fitted by British Airways with the Lorenz and that pilots would not leave unless the set was serviceable.

To the speaker's knowledge, no landings had yet been made with the system over water. He thought the main difficulty was that of siting the marker beacons. It was obvious that the mast gear for the aerials must be absolutely rigid, otherwise the marker would be wobbling all over the place, and this appeared to be the chief difficulty.

Replying to Captain Furnival, the lecturer said that his own opinion was that a track width of 4 degrees which gave a width of 86 yards at a distance of 1,300 yards was the ideal. He had flown on a beam which had a width of 1½ degrees and found it extremely difficult to hold. Possibly one of the reasons was that the directional gyro at the moment was calibrated every 5 degrees, and one could not very well hold absolutely on one degree. A beam width only 1½ degrees wide caused wobbling and one never settled down.

As regards back radiation, he definitely liked it. Once in the beam, he liked to stay in it and the only time he went out of it was when he flew off on his plus 30 course; even then he went out only for a short time, and that was the whole idea of doing that accurately rated turn which brought one back into the centre of the beam without any major alteration in direction.

He was afraid he had had no experience of the automatic pilot, but he did not see why it should not be applied to either system. It was rather out of his province.

In conclusion, he wished to thank all those who had kindly praised his paper, and particularly the members of the Royal Aircraft Establishment, who had taken a lot of trouble in drawing his pictures, photographing them and making lantern slides. He specially thanked Mr. Cox Walker for checking his paper and preventing him from falling into any very deep pitfalls and would like to thank Flight Lieutenant M. J. Adam for all he had done as " Safety Pilot " throughout the hooded experiments during the summer of 1936.

The CHAIRMAN: He wished first to thank all those speakers who, during the discussion, had kept so skilfully to the time limit he had suggested. This had enabled the meeting to hear so many more points of view than would otherwise have been possible.

Referring to the complaint that modern aeroplanes did not seem to be sufficiently stable laterally, he considered this was due in certain types to the fact that when the designers designed the machines, they did not fully appreciate the effect on lateral stability of sweep forward or sweep back when tapering their wings.

The importance of this was more realised now, and he imagined that that criticism as to inadequate lateral stability would not need to be levelled against newer designs.

He did think that the aeronautical community had some cause to pat themselves on the back, and he would like to pat on the back those who deserved it now. He was thinking particularly of the contrast of their point of view with that of the marine engineer. Only a short while ago, he himself was in a ship for four hours at anchor only a few miles from port with a visibility of several hundred yards, because the captain did not like to go forward, even at the very lowest speed. After so many years of operating ships that seemed a scandalous

state of affairs, and he saw little hope of relief until the aeronautical people had shown the way. That was a point worthy of note because the problem in the air was infinitely more difficult than on the water. At least, on the water one could stand still and scratch one's head and think about things, but one knew what happened if one took their eyes off their instruments even for a moment and had a chat with the people in the cabin standing near.

The tremendous importance from the Service point of view of such aids to flying as they had been discussing needed no emphasis from him now. In the old days the Navy was pre-eminent, largely because seamen could keep the sea when the navies of other countries were driven to seek shelter. Is that piece of history going to repeat itself in the air? If the Royal Air Force could fly when opposing forces were earthbound, surely that would be a factor of absolutely overwhelming importance. Of course, they all hoped that the hour of need would be postponed indefinitely, perhaps till the time when no pilots at all would be needed, having been replaced by instruments and ground control, while a chief charwoman polishing up the faces of the instruments would form the most important part of the crew.

But that day was far enough off. Obviously they must in the immediate future look to their pilots to carry out the necessary duty of landing, as well as flying. As they had seen, it needed in bad weather a very high degree of skill to do this, and also a high degree of courage and determination. They had heard an excellent account of this work from a pilot who had actually taken part in it, and no words were needed from him (the Chairman) to urge them to accord Squadron Leader Blucke an extremely hearty vote of thanks.

The vote of thanks was accorded by the large audience with acclamation.

Mr. D. N. SHARMAN (*Communicated*): Squadron Leader R. S. Blucke in his recent lecture on " Radio as a Direct Aid to Landing Approach " enumerated several aspects of the blind approach and blind landing problems at the present moment.

Of particular interest was the reference made to the unsuitability of the beam to render an indication of the gliding angle.

By the kind permission of the Air Ministry in 1935, the writer carried out several experiments with a subterranean beacon in the north west corner of Croydon Aerodrome.

It was observed that the uniformity of the gliding angle indication was unreliable and the readings on the field strength meter varied from day to day according to the hygroscopic content of the atmosphere and the conductivity of the earth.

Recently, similar experiments with subterranean horizontal antennas have been carried out by Messrs. Diamond and Dunmore, of the United States Bureau of Standards (Proc. I.R.E., Vol. 25, No. 12., Dec., 1937, P. 1542.).

The landing technique adopted by Squadron Leader Blucke could be considerably simplified if a unidirectional landing path were utilised.

Moreover, an additional marker beacon placed at a distance of approximately four miles from the aerodrome would be a great help to the pilot. Such a procedure was suggested by the writer as far back as November, 1933, in British Patent No. 428,681.

In his opinion the ideal blind approach and landing scheme should possess the following features:—

1. Guide beam preferably unidirectional, range 30-40 miles. If a reciprocal corridor is provided the transmissions should be designed in order that the dashes are always transmitted on the right side while the dots are always transmitted on the left side when the aeroplane is heading towards the aerodrome.
2. Due to frequency restrictions, and in order to simplify receiver design, all the main beacon transmissions should be transmitted on a single frequency of nine metres.

3. To avoid interference from aerodromes situated in close proximity an indication of the name of the station of approach should be given to the pilot.
4. Absolute blind landing aid should be provided to the pilot by utilising the 7.85 metres frequency.
5. Another marker beacon situated about four miles from the aerodrome should also be provided.
6. It is agreed that for blind approach purposes a 4° width of the approach corridor was ideal.

All the requirements enumerated above are practically possible. It is hoped that an installation in conformity with the requirements indicated above will be installed and available to the aeroplanes at one of the aerodromes in the near future.

Air Commodore P. F. M. FELLOWES (*Associate, Communicated*): The great value of this clear analysis by a practical exponent is apparent to everybody, but what he ventured to suggest was not so apparent were the things he had left unsaid. To clear his own mind in some of these things he would like to ask the lecturer the following five questions.

1. Can he give them any idea of the state of nerve stress induced in blind landing?
2. Does this nerve stress decrease appreciably as the reaction to visual signals and sounds becomes more and more automatic?
3. Does he consider the standard of nervous fitness required is normal or super-normal, to make a successful blind landing pilot?
4. Has he any experience to enable him to say for how long the reactions, once trained, remain trained? In the United States they advise a test for the blind flying efficiency of commercial pilots every 60 days. Is this allowing enough margin to include the average or does he think it errs on the side of safety?
5. Does he agree that in both blind flying and blind landing, the ideal to be aimed at is so to train the subconscious reactions that no conscious thought is required?

In reply to Air Commodore Fellowes' questionnaire, my opinions are as follows:—

1. Considerable concentration on the instruments is of course necessary. I consider that the amount of concentration decreases with practice and experience with a consequent increase of confidence in instrumental flying generally.
2. Yes. I consider nerve stress does diminish with experience and familiarity with the system.
3. I consider the standard of nervous fitness is quite normal and requires no higher standard than that demanded by the medical authorities for normal flying.
4. I regret I have no information on this point. But, I think this depends on constant flying practice and constant instrument flying. A fully trained pilot, flying even only 20 or 30 hours a month, should find no difficulty in keeping in practice. As an instance I quote my own case, namely:—That 32 days elapsed between making a hooded approach and making an actual fog landing in 1936. During those 32 days I had of course been flying regularly. I should hesitate to criticise the American regulations which appear to me very sound for commercial safety.
5. Yes. I agree that blind flight and landing must become as automatic as normal flight by vision.

The 630th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, Westminster, London, S.W.1, on Thursday, February 3rd, 1938, at which a paper by Mr. Ernest F. Relf, A.R.C.Sc., F.R.Ae.S., F.R.S., on " Recent Research on the Improvement of the Aerodynamic Characteristics of Aircraft," was presented and discussed.

Mr. D. R. Pye, M.A., F.R.Ae.S., Vice-President, in the chair.

The CHAIRMAN: It was a notable feature of aeronautical engineering that even the most advanced results of aerodynamic research lay very close to the fairly clearly defined needs of the aeronautical engineer and designer; moreover, as the technique of design and construction advanced the margin of improvement to be achieved by further research did not diminish. In that respect aeronautical engineering was unlike some other branches of engineering where, as the technique of design progressed, the margin for further improvement became less and less. Not so long ago one considered the cleaning up of designs almost in terms of using a hatchet for chopping off the excrescences. Now Mr. Relf was recommending the use of a fine polisher, and the effect of the surface finish upon performance was of the same order as the effect of using a hatchet in the old days.

There could be no real conquest in the realm of design and construction except on the basis of scientific work; but although such work might be planned with a view to giving results very close to the needs of the engineer, there was at the same time a gap, which was deep rather than wide, between the establishment of scientific results such as Mr. Relf would describe and the realisation of those results in the actual aeroplane. That gap could be bridged only by constant collaboration and discussion between the engineers and the research workers, the sort of discussion which could take place ideally at a meeting such as that of the Royal Aeronautical Society. He hoped that there were some designers present who would offer their criticism and express their views upon the planning of future work.

There was a further point to which he would like to draw attention. In the diagrams illustrating Mr. Relf's results, with the points lying so nicely on the curves, it all looked rather easy and there was no indication of the difficult technique necessary for obtaining these results. He would urge that anyone who had not seen the compressed air tunnel at the National Physical Laboratory, and could find an opportunity for doing so, should acquaint himself with the very wonderful technique developed by Mr. Relf and his staff on which the possibility of obtaining the sort of results they would be shown that evening, wholly depended.

RECENT RESEARCH ON THE IMPROVEMENT OF THE AERODYNAMIC CHARACTERISTICS OF AIRCRAFT.

ERNEST F. RELF, A.R.C.Sc., F.R.Ae.S., F.R.S.

The object of the present paper is to draw attention to some of the recent researches which have had as object the improvement of the aerodynamic characteristics of aircraft. Such characteristics can be classified into two groups; those concerned with performance and those concerned with stability and control. In the former group come all those researches which aim at the reduction of drag, while in the latter group come those directed to the attainment of satisfactory stability and control in normal flight, as well as those concerned with the behaviour of auxiliary devices such as flaps and slots which are used under special conditions and in particular during landing and taking-off. The problems associated with flutter also belong to this group. The two groups may be broadly characterised by the words *economy* and *safety*. Drag reductions enable us to attain greater range or greater speed with a given power unit, but these advantages are of doubtful value unless at the same time we can insure safe operation under all conditions of flight.

Almost the whole of present-day aerodynamic research could be legitimately classified in one of the above two groups, and the field is so wide that I can do no more in the course of a single lecture than to select a few of the researches on which attention is most strongly focussed at the moment, to show what is the present state of knowledge upon them, and to indicate the next steps towards further understanding of the problems involved.

Perhaps the most outstanding tendency of aeroplane design at the present time is the continued effort towards the attainment of higher and yet higher speeds. Ever since 1927 when Prof. Melvill Jones (1) pointed out so clearly the deficiency of the aeroplane of that day there has been a gradual process of "cleaning up" the aeroplane from the point of view of drag. Closed cockpits and retracted undercarriages, which were not so long ago dismissed as practically impossible, are now commonplace, and the aeroplane has been reduced almost to the limit of simplicity of external shape.

Apart from the induced drag of the wings, the drag of the modern aeroplane is very largely due to skin friction, and if only our knowledge of skin friction were complete, the problem of drag estimation would be a very simple one. It is rather a humiliating thought that after so many years of research we are still unable to estimate, with a reasonable degree of engineering accuracy, what will be the drag of a new type of aircraft, or, for that matter, even what will be the drag of its fundamental component part, the wing. Intensive research is at present in hand to remove this disability and such research has been immensely facilitated by the development of the momentum or pitot-traverse method of drag measurement. There is no need for me to describe this method, which was so ably treated by Prof. Jones in his lecture before the Society on December 17th, 1936 (2), and which is rapidly becoming familiar to all those interested in drag measurement, but I should like to commence by showing some of the recent results obtained by its application in the compressed air tunnel and to trace the connection between these results and those obtained in free flight experiments.

PROFILE DRAG FROM THE COMPRESSED AIR TUNNEL.

By use of the pitot-traverse method it has been possible to extend very considerably the range of Reynolds number over which drag measurements could be made. The standard chord of aerofoils for use on the balance is 8ins. and gives an upper limit of Reynolds number of about 8×10^6. By using a chord of 2 ft. and traversing the centre section with the pitot tube, this limit has been raised to about 24×10^6. As far as I am aware, this is the first time that drags have been measured in the laboratory at Reynolds numbers above 10^7. The pitot

tube was traversed by means of a repeater of the " Selsyn " type, in which a small " motor " follows the rotation of a distant " generator " by the well-known device of coupled three-phase rotors working in a single-phase alternating field. The pitot pressures were measured by a manometer, similar to that used for speed measurements in the tunnel, in which the transfer of liquid in a large bore U tube is weighed by mounting the whole tube on an electric balance.

After some measurements on aerofoils had been made I suggested that it would be an excellent check on the method to use it to determine the drag of a flat plate, and it will be convenient to consider the flat plate results first. The plate was of aluminium, $\frac{1}{8}$ inch thick and 2ft. wide, with an elliptical leading edge and a sharp trailing edge. The results are given in Fig. 1 and it will be

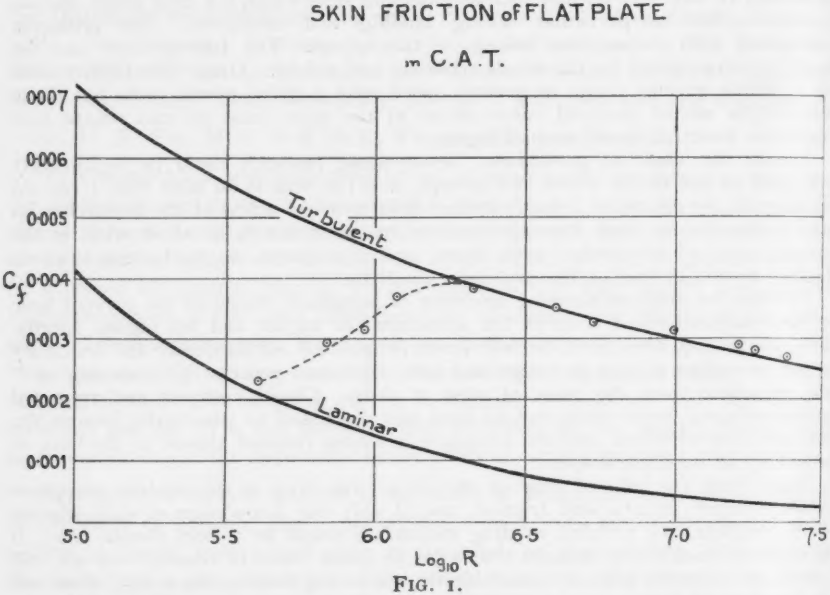


FIG. 1.

seen that at Reynolds numbers above 3×10^6 they lie very close indeed to the generally accepted curve given by the formula

$$C_f = 0.455\ (\log_{\cdot 10} R)^{-2\cdot 58}.$$

Below 3×10^6 they lie on a transition curve, as would be expected, and reach nearly to the laminar curve at the lowest Reynolds number. The work provides an excellent check on the accuracy of the method and gives confidence in its use for studying aerofoil drag. It is also of great interest, in that the flat plate formula is based on tests in water, and is now confirmed very closely by tests in compressed air.

Turning now to the case of the aerofoil, the results obtained with symmetrical aerofoils are given in Fig. 2. The behaviour, even with a thickness/chord ratio of 12 per cent., is remarkably different from that of the flat plate. The drag does not even approximate to that of the flat plate with laminar flow at low Reynolds numbers, and there is no marked evidence of the transition region. These differences, as Prof. Jones pointed out (2), are associated with the effect of the curvature on the transition from laminar to turbulent flow in the boundary layer and with the existence of a superimposed " form " drag due to the resultant of the normal pressures on the surface. It does not seem possible to explain

these effects in detail at present, but an attempt is to be made in the compressed air tunnel to measure the transition point and the form drag on at least two aerofoils of different thickness in order to see whether theories of laminar and turbulent skin friction will then enable the behaviour to be analysed completely at all Reynolds numbers.

From the point of view of the present paper, the most interesting feature is the way in which the drag curves tend to follow the slope of the flat plate curve at high Reynolds numbers This tendency is a little less marked for the 0012 aerofoil than for the thicker ones. The 0012 aerofoil was a wooden one, of 18ins. chord, and it is possible that it was slightly rough under high pressure. Wood

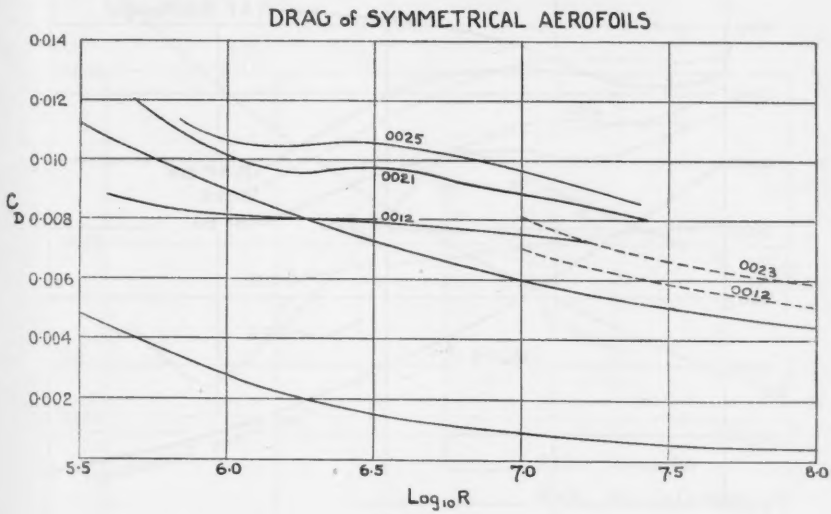


FIG. 2.

has been found to be somewhat unsatisfactory in the compressed air tunnel, the high pressure tending to compress the hard and soft parts of the grain unequally and so leading to the development of slight ridges on the surface. It will be interesting to repeat this test on the metal aerofoil of the same thickness which is being prepared for the drag analysis mentioned above. The tendency to follow the flat plate curve at high Reynolds numbers suggests that the aerofoils are aerodynamically smooth, and that most of the boundary layer has become turbulent, or at least that the transition point is no longer changing its position much with change in Reynolds number. The two dotted curves on the right of Fig. 2 are calculated values of the skin friction component of the drag, based on the assumption that the boundary layer is wholly turbulent. Roughly speaking, the measured excess of drag above that of the flat plate is twice the calculated excess, and it is presumed that the difference is due to the form drag. We shall return to this point later.

The curves of Fig. 3 show a number of results for cambered aerofoils. The three curves for the symmetrical aerofoils of Fig. 2 are shown dotted and can be compared with the C.A.T. results for the two thick aerofoils R.A.F.69 and R.A.F.89 which have the same thickness/chord ratio as the two thicker symmetrical sections, but have a 2 per cent. centre line camber. The tendency of the symmetrical sections to have a higher drag than the cambered ones at low Reynolds numbers is presumably due to the transition point being further back on the more highly curved upper surface of the cambered aerofoils. At high

Reynolds numbers there is no measurable difference due to 2 per cent. camber on the 21 per cent. aerofoil, but at a thickness ratio of 25 per cent. the cambered aerofoil appears to have a slightly higher drag than the symmetrical one. A single test was made on the R.A.F.89 section roughened with 0.0004 in. grains of carborundum powder, and shows the marked departure from the smooth curve at high Reynolds numbers previously established by balance tests on 8 in. chord aerofoils (3). It emphasises again the extreme importance of smoothness of

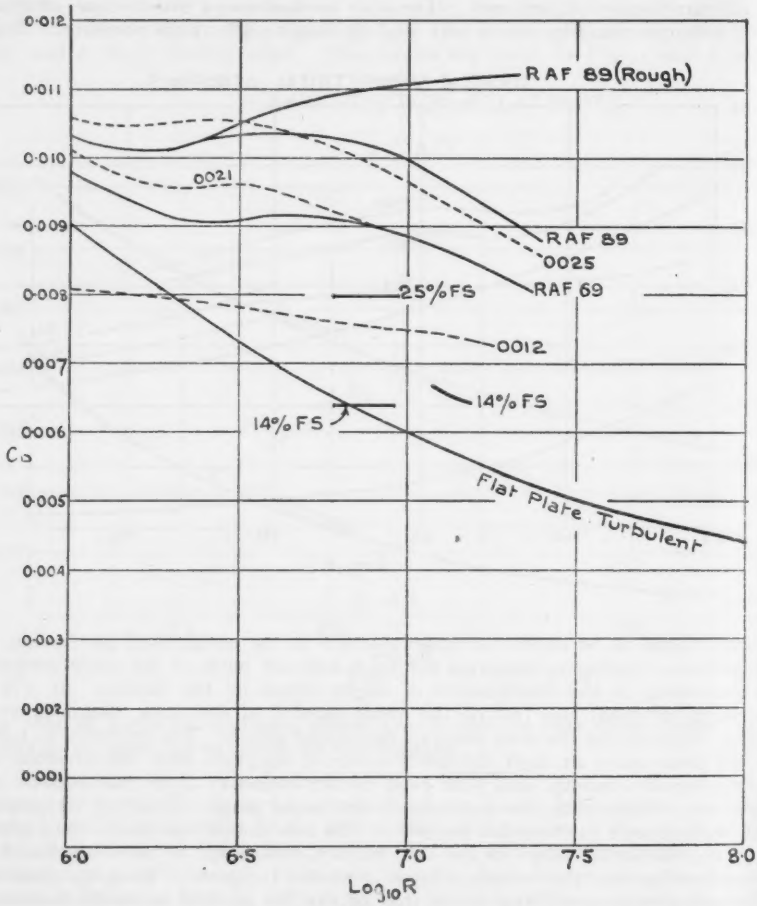


FIG. 3.

Drag of Cambered Aerofoils.

surface for high speed aircraft, for the degree of roughness used corresponds with excrescences little more than one-thousandth of an inch in size on a full-scale wing of moderate chord.

There are as yet only a few available flight tests on the profile drag of smooth wings determined by the pitot-traverse measurement, but these show a marked difference from the tunnel results, the drag coefficient being decidedly *lower* at the same Reynolds number. In Fig. 3 two such recent determinations for wings 14 per

cent. and 25 per cent. thick have been included for comparison. The drag coefficient is in both cases lower by about 0.002 than the model results. The reason for this is now well known, and lies in the fact that under the non-turbulent conditions of the free air the transition point, where turbulent motion develops in the boundary layer, is much further back on the chord than in the more turbulent flow of the tunnel. Even at a Reynolds number as high as 15×10^6 the transition point on the upper surface has been observed in flight as far back as 0.35 chord. On the lower surface it may be at about 0.3 chord for low lift coefficients. The transition point

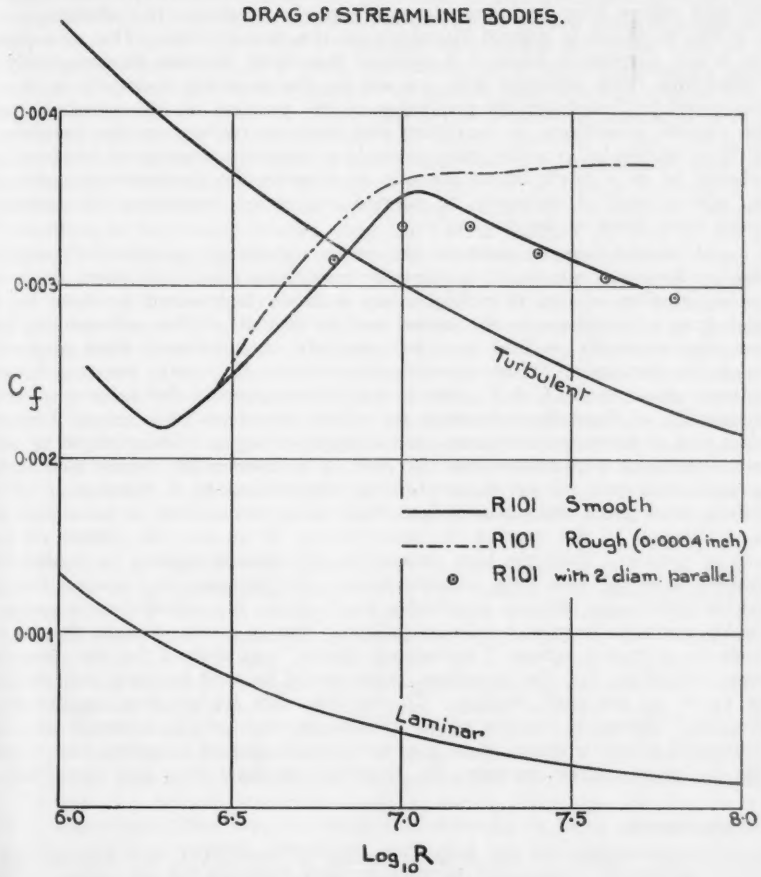


FIG. 4.

on the upper surface is known to be in a somewhat sensitive condition at the higher Reynolds numbers. An exceedingly small ridge near the leading edge will make it go forward, and so will the disturbed conditions behind an airscrew. It has been calculated that if the transition occurred on both surfaces at 0.15 chord in the case shown in Fig. 3 the drag coefficients would have been increased to about the values observed in the C.A.T. tests. There is thus no mystery about the low drag found in flight tests on smooth wings; the only problem is to determine how far it is possible to achieve these low drags under practical con-

ditions. It is quite evident that smoothness of surface is essential and also that the front third of the surface should be kept free from any kind of local excrescence, such as a joint between two plates or a " ripple " in the plating. It is almost certainly impossible to retain the far back transition in the slipstream, and so a higher wing drag must be expected when a large fraction of the wing area lies behind airscrews, as it does with a tapered wing on a two or four-engined machine.

It is now possible to calculate with fair accuracy what the skin-friction component of the drag will be if the point of transition is known. It also appears likely that before long the form drag will prove amenable to calculation, and that it will be found to depend intimately on the skin friction. That this should be so is not surprising when it is realised that drag depends fundamentally on the departure from potential flow caused by the retarded boundary layer. If means could be found for the prediction of the position of the transition point under various conditions of curvature and external turbulence, the problem of wing drag would be in a fair way towards a complete theoretical solution, and we should be in a much better position as regards the interpretation of model tests, which must of necessity be carried out under conditions of turbulence different from those of the free air.

A word should here be said on the present American practice of using an " effective Reynolds number " to allow for turbulence effects, in which the actual Reynolds number of test is multiplied by a factor determined by tests on the critical drag of a sphere in the tunnel and in free air. This process has been shown experimentally to lead to a fair measure of agreement when applied to tests on the maximum lift of aerofoils of moderate thickness, but it is known, from tests made in the C.A.T., that it would not apply in the same way to the maximum lift of those thick aerofoils for which the effects of increased Reynolds number and of increased turbulence are of opposite signs. There might be some reason to expect a correlation in the case of maximum lift, since both sphere drag and maximum lift of an aerofoil are determined by a breakaway of the boundary layer from the surface, but there is no reason at all to expect any such correlation in the case of the skin friction of an aerofoil, where no such breakway occurs. That the idea cannot be legitimately applied to profile drag is evident from the following considerations. Flight tests have shown that the transition point may remain practically fixed at say 0.3 chord over a range of Reynolds numbers from say 5 to 10 million. But it is also known that at five millions in a tunnel whose " turbulence factor," as defined by the American scheme, would be 2.0, the transition point would be well forward and the drag some 15 or 20 per cent. higher. To say that this higher drag applies at an " effective " Reynolds number of 10 millions is obviously in contradiction with the observed full-scale result, even if a correction is applied based on the variation of the flat plate friction between the Reynolds numbers of 5 and 10 millions.

Drag of Bodies.

Some recent results on the drag of bodies in the C.A.T. are summarised in Fig. 4. It will be noted that the general characteristics of the curves at high Reynolds numbers are similar to those for aerofoils, but that the transition region of drag is now almost as marked as in the case of the flat plate. The agreement of the full curve with the points shows that the drag per unit area of surface is not altered by a considerable change of shape and fineness ratio. In fact, at high Reynolds numbers, all bodies of reasonable form have a drag approaching skin friction, in marked contrast to the variations found in older tests, which were all made in the transition region. The effect of roughness of surface is shown in one case, and is again similar to that produced by roughness on an aerofoil. It would therefore appear that all the general arguments with respect to wing drag may be expected to apply to bodies also. It is as desirable to keep the

surface smooth as in the case of the wing, and any local irregularities in surface over the front part of the body should be avoided, especially if it is not in the slipstream. The inevitable break in the " lines " of the body caused by the cabin top need not lead to any appreciable increase of drag if the cabin surface is smooth and if the fairing to the rear is sufficiently long.

INTERFERENCE DRAG.

When the wing, body, tail surfaces and nacelles are combined to make the complete aircraft, there arise all the problems of interference drag, and here it is not possible in the present state of knowledge to give a definite guide to the designer in all cases. Now that design has approached the lower limit of drag attainable, the importance of a small interference drag is proportionately greater than it used to be, and further research is needed, and is being carried out, on some of the problems involved. The question of body-wing interference is probably the simplest, and it now appears that unless the wing is very thick, or is placed very low on the body, there is not a likelihood of a large interference effect. Unfortunately, from this point of view, the tendency of design is towards both unfavourable conditions, the thick wing being attractive structurally, especially for machines of high wing loading, and the lowest possible position of the wing being a great help in the design of a short and easily retracted undercarriage. The type exemplified by the Heinkel He 70 in which the low-wing roots are normal to the elliptical body section meets both difficulties, and appears to be excellent aerodynamically, but at the cost of the increased difficulty of constructing a wing with curved spars. The variations are so many that it is not possible to give general rules. The only course is to resort to the wind-tunnel for guidance in doubtful cases, and the general ideas now current on the avoidance of rapid " expansion " between surfaces are generally sufficient to enable doubtful cases to be recognised as such. In this connection it is probably true generally that an interference effect tends to " clean up " with increasing Reynolds number, so that if a model is modified in an ordinary wind tunnel until the interference drag is small it is very unlikely that the full-scale will prove worse in this respect than the model.

The problem of nacelle-wing interference is more difficult and it is here that further research is particularly desirable. The nacelle is essentially a body of comparatively low fineness ratio, compared with the fuselage, and there is accordingly much more likelihood of separation of the flow in the " divergent " region between the rear part of the nacelle and the wing surface. This is particularly the case with a small high-powered twin-engined machine, when the nacelle diameter, as a fraction of the wing chord, becomes large. On large machines there should be no difficulty in making the tail of the nacelle long enough to avoid a serious breakaway of flow, but there is still the problem of designing the nose of the nacelle, in the case of the air-cooled engine, so that it still behaves as a smooth streamline body as far as disturbing the flow over the wing is concerned. One way in which this difficulty is being surmounted is to make the nacelle a smooth streamline body and to duct the cooling air from " pitot " inlets on the adjacent leading edge of the wing. Obviously anything the engine designer can do to reduce the lateral dimensions of the engine is an enormous help in nacelle design. The ultimate answer is probably an engine which will go into the *essential* shape of the aircraft, so to speak, without requiring external bulges, aerodynamically unnecessary, to house it, but this ideal is not likely soon to materialise.

Of the problem of cooling drag I am not well qualified to speak, and in the present position as regards published details of recent research I can only mention it in passing, and express the hope that, when the time is ripe, someone who has been intimately connected with this work will give you a comprehensive review of what has been achieved. It has been demonstrated theoretically that at speeds

somewhat in excess of 300 miles per hour it should be possible to get enough cooling at no expense in drag. In practice it is not at all easy to realise the necessary conditions, but a steady advance is resulting both from general research on the subject and from tests on specific designs with an eye to their improvement. It does not appear unreasonable to hope that something close to the theoretical optimum will be commonplace before very long.

Drag Tests of Complete Models.

During the last few years a considerable number of complete models have been tested in the compressed air tunnel at high Reynolds numbers. The results obtained cannot be given yet in detail, but, by the kind permission of the Director of Scientific Research, Air Ministry, I am able to present a summary of them and to draw some conclusions of general interest in indicating the present state of the approach to what we consider the " ideal " low-drag aeroplane.

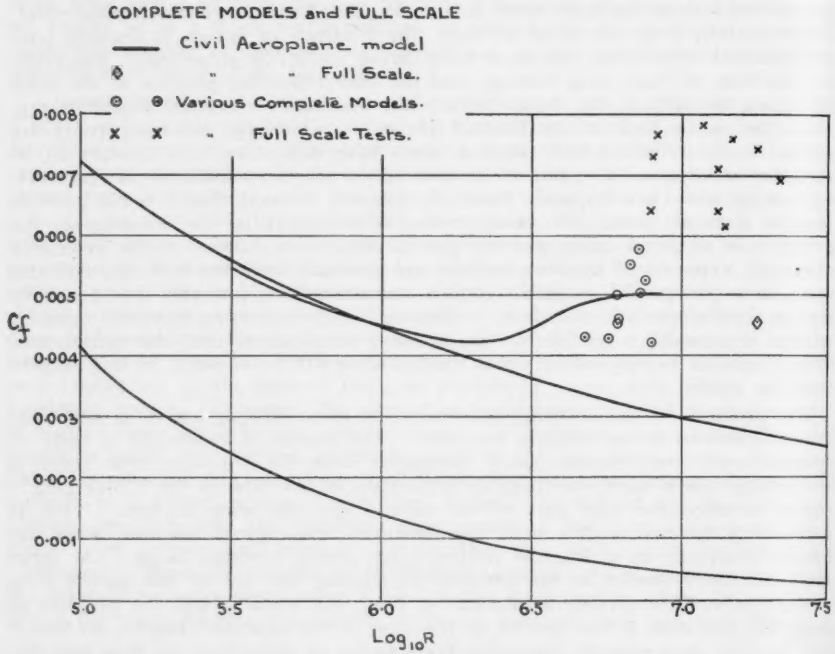


Fig. 5.

The diagram given in Fig. 5 shows in a very general way the present state of affairs. The full curve is a test of a model of a civil aeroplane over the whole range of Reynolds number available in the C.A.T. The full-scale point is from a performance test in flight. It will be seen that if the model curve bends down at Reynolds numbers above say 8×10^6, as do the curves for aerofoil drag previously shown (Fig. 3), it will pass very close to the full-scale value of the drag. The aeroplane in question may be regarded as a crucial experiment to see what would actually be achieved in drag if all the surfaces were made smooth and continuous. The answer appears to be that if this is done the drag is certainly not higher than would be predicted from the test of a smooth model in the C.A.T. There is some ground for supposing that it ought to be appreciably lower than the tunnel prediction, since it is known, as has already been pointed out in this

lecture, that the transition point can be further back in free air than in the more turbulent air of the tunnel.

Returning to the diagram, the points shown by circles represent the drags of a number of complete models expressed as coefficients of skin friction on the total " wetted " area. They cluster round the value for the civil aeroplane, some few being appreciably lower than for that aeroplane. It must not be assumed that the higher points necessarily represent worse aerodynamic design than the lower ones, since the models tested represent all types of machine, and in some cases higher drags may have been unavoidable on account of the operational requirements of the type in question. The points marked by crosses represent a number of results of full-scale tests on modern types of aeroplane. It is at once apparent that the drags characteristic of the smooth models in the C.A.T. have not yet been generally realised in practice, but the case of the civil aeroplane shows that they are attainable when everything is sacrificed that would in any way prevent the attainment of smoothness. That the ideal has not been attained more generally is by no means surprising; the surprising thing is that our designers have done so well in the face of the innumerable difficulties inherent in meeting operational needs while still preserving the best approach to smooth and unbroken surfaces. Had I plotted on the diagram some drag figures for aeroplanes of five years ago the improvement effected in present-day machines would have been strikingly apparent, for such points would have been well above the top of the figure. Can the ideal be more generally attained? I think it can, and I think it will, by the gradual refinement of constructional methods.

We can already see signs of such a steady advance; methods of riveting are continually being improved to give more nearly a flush finish, more attention is being paid to continuity of surface where plating must be removable for access or where it must close over a retracted undercarriage, and details such as the small gaps at control surface junctions are being more carefully considered. The necessity of smooth surfaces having once been thoroughly demonstrated beyond all question, design will ultimately triumph over the admittedly great practical difficulties, but the process must of necessity take its time.

Stability and Control.

It cannot yet be said that knowledge of stability and control is in a satisfactory position. While calculations of performance have to-day at least a reasonable numerical accuracy, those relating to stability are far less definite, nor have we yet any satisfactory way of stating numerically what is the desirable degree of stability for an aeroplane of a given type. The problem has been made more difficult than ever in recent years as a result of two causes. In the first place the increased power loading makes slipstream effects more important, especially over the lower part of the speed range, and in the second, the use of landing flaps raises questions of trim which are intimately bound up with stability. Research on the subject is being carried out both on models and on full-scale aeroplanes, but much remains to be done before anything like a complete review of the problem becomes possible. The position, from the scientific point of view, is aggravated by the change to the monoplane. In past years a great deal of data had been collected on the stability derivatives of the conventional biplane, but as yet there is nothing approaching the same amount of data available for the modern monoplane.

Longitudinal Stability.

In a sense longitudinal stability is the most important, since motion in the plane of symmetry is mainly concerned during the most difficult moments in the flying of an aeroplane, namely, while landing and taking off. Fortunately, it is also the simplest of stability problems, from the analytical point of view. What is required is a reasonable degree of stability over the whole speed range, or,

put aerodynamically, a small, constant negative slope of the curve of pitching moment against lift coefficient. This was comparatively easy to attain with the old thin-wing biplane, but is becoming increasingly difficult to get on modern monoplanes. There are a number of reasons why this is so. The two chief reasons lie in the effect of the body and nacelles in causing non-linearity in the pitching moment curve, and in the large variations of position of centre of gravity which have to be met in some types, due to the high value of the disposable load and to the necessity of meeting different operational requirements in the same machine. It has been shown by model experiments that with low-wing monoplanes the interference effects of the body and still more of the nacelles may lead to considerable departures from linearity in the moment curve, with the consequence that if the tail is made powerful enough to give stability at all speeds there will be excessive stability at some speeds. It is possible to combine the wing, fuselage and nacelles so that this effect does not occur to any marked degree, but no general rule can be given. In practice the difficulty arises that the best aerodynamic combination may not be acceptable, as it may not permit such operations as the retraction of the undercarriages into the back part of the nacelles.

The effects of a large C.G. range are more serious. If it were only necessary to use a large enough tail to secure stability with the C.G. at the aft limit, the result would be merely a somewhat high degree of stability for the forward C.G. limit and a small extra drag due to the large tail. But the large tail has other disadvantages of much greater importance. It involves a change of trim when the flaps are put down, and it involves larger changes of trim due to ground effect when landing. The span and chord of split flaps does not vary greatly from one machine to another and consequently the pitching moment change on the wing due to putting the flaps down does not vary much, nor does the increment of lift, and consequent increment of downwash, due to the flap. It follows that there is a certain tail volume which leads to an approximate balance between the additional wing moment and the additional tail moment due to downwash change. If the tail is made smaller than this, as it might be for a machine whose aft C.G. position was not very far back, then the machine is liable to be nose heavy when the flaps are used. On the other hand, a large and effective tail designed to secure stability with the C.G. very far back leads inevitably to tail heaviness when the flaps are put down. Put in another way, if the flap and tail are designed for no change of trim, the furthest back position of C.G. for stability is thereby defined.

The effect of the proximity to the ground at landing is of a similar nature, since it involves a large change of downwash at the tail. The downwash change must obviously be a decrease, since the flat surface of the ground limits the downward component of velocity behind the wing. The effect is therefore to make the machine nose heavy, and to render it harder to get the tail down by the use of the elevators. A large and effective tail with weak elevators is therefore liable to give trouble in this respect. It is of interest to notice that these two effects are of opposite sign, and that if any change of trim due to flaps is allowed it should be in the direction of tail heaviness, for then, if the change of trim is counteracted by a more positive elevator setting, it automatically leaves more negative elevator range available to get the tail down against the effect of the ground downwash change. It also allows a further back C.G. for neutral stability.

The question of longitudinal stability with free elevators is one of some importance on which more work could advantageously be carried out. Irving has shown (4) that the change of stability due to freeing the elevator can be of either sign, depending on the nature of the changes of elevator hinge moment due respectively to change of elevator angle and to change of incidence of the aeroplane. It does not seem impossible that some scheme of elevator balance could be devised which would result in no change of stability when the elevator was freed, and this would appear to be a desirable characteristic to attain.

It does not, of course, follow that a negative slope of the pitching moment curve is a sufficient criterion of longitudinal stability; it is still possible, but fortunately rare, for the phugoid motion to be unstable. The complete consideration of longitudinal stability is not prohibitively difficult. A knowledge of lift, drag, and pitching moment as functions of incidence is usually available and from these data all the important stability derivatives can be calculated with the exception of the damping derivative M_q. A fair estimate of M_q can be made, and the stability of the phugoid is not critically dependent on either M_q or the moment of inertia.

The effect of the slipstream on longitudinal stability is a serious problem, and there is not yet enough information to enable it to be calculated with any precision. It is known that in different types of aircraft the effect may be either stabilising or destabilising and that the magnitude of the change may sometimes be large enough to be of importance. Research is in hand on a model of a typical monoplane in order to collect data on this question, and to endeavour to devise some general method of dealing with the problem in practice.

Lateral Stability in Normal Flight.

As far as I know no serious attempt is ever made to calculate lateral stability, and the reason is not far to seek. The number of important derivatives is greater than for the case of longitudinal stability, and most of them are very difficult to determine by model test and are not susceptible to calculation with anything like the precision of the longitudinal group. What is usually done is to provide " weathercock " stability, *i.e.*, to make the yawing moment due to yaw stabilising, and to use a certain amount of dihedral angle. This process has generally resulted in lateral stability for normal flight, but there are certain things that may lead to its failure, particularly in the case of the low-wing monoplane. It has recently been shown that in a tapered low-wing monoplane the effective dihedral angle is less than the geometric dihedral angle. In one case, a model with 5° dihedral proved to have zero effective dihedral angle, *i.e.*, there was no rolling moment due to yaw. The effect was traced mainly to the asymmetric changes of flow over the wing roots due to interaction with the body when yawed, though perhaps a little was also due to the taper of the wing itself. When the model was converted to a high-wing type, its behaviour as regards effective dihedral was normal. It would thus appear that the low-wing type requires in general a larger geometric dihedral than the high-wing type or the older biplane. The tendency of some modern designs towards a rather large degree of weathercock stability aggravates the effect and demands a still larger dihedral angle for stability.

Lateral stability is affected by the mass distribution, but not critically. It is more difficult to attain stability when the weights are mainly concentrated along the wing span than when they are mainly concentrated along the length of the body, and the difficulty increases with increase of wing loading.

An attempt has recently been made at the N.P.L. to devise a means whereby the lateral stability of a model can be directly determined in a wind tunnel by a simple test. The model is suspended in a particular way at the lower end of a long rod, and certain conditions regarding the weight of the model and its mass distribution must be observed. It has been shown mathematically that under these conditions the lateral motion is a fairly close representation of what occurs when the model has complete freedom. Only a few tentative tests have been made and it is not yet possible to say whether the method will prove a success. It is analogous, in a way, to the use of the free spinning tunnel to obtain a direct indication of the spinning characteristics, and incidentally, it suffers from the same disadvantage as the spinning test, namely, that the Reynolds number is of necessity rather low. There is, however, no doubt that if it can be developed to a satisfactory state, it would prove most valuable in the study of stability, just as the spinning analogue has done, in spite of its limitations, in the study of spinning.

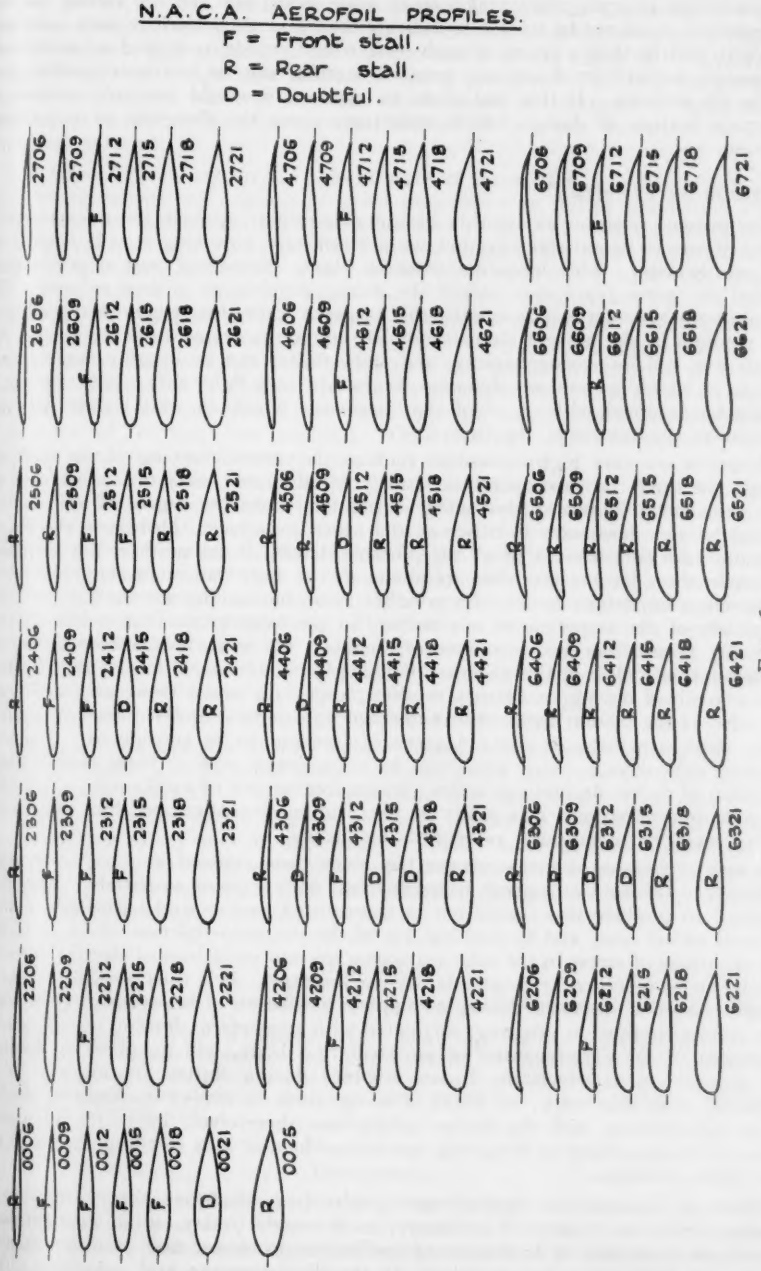
LATERAL STABILITY NEAR THE STALL.

This problem has been with us for many years, and has long been recognised as one of much importance as regards safety. In practice it reduces largely to the tendency usually known as " wing dropping." Near the stall the rolling motion can become violently unstable, a wing drops rapidly, and if the machine is near the ground an accident may result from insufficient height for recovery. This effect can hardly be classified as an instability in the sense of the classical theory of small oscillations, it is rather due to asymmetric stalling of the portions of the wings near the tips, leading to large and sudden rolling moments on the machine. It can, as was shown long ago, be completely cured by preventing the tips from stalling until an angle of incidence considerably in excess of that at which the centre portions of the wing stall, *e.g.*, by the use of wing tip slots. It can also be obviated by a " wash-out " at the tips, but this is not a satisfactory solution, as the wash-out necessary is so great that it results in a serious disturbance of the lift grading at top speed and a consequent increase of induced drag in the condition where such an increase is least desirable.

In spite of the effectiveness of tip slots, and of the possibility of an appreciable increase of overall maximum lift by their proper use, the tendency of present day design is to avoid slots. They introduce an additional moving part and they hinder the attainment of an undisturbed surface, since it is not easy to make them close perfectly on a structure so flexible as a wing. The designer would prefer to attain freedom from wing dropping purely by modification of wing tip shape, if that were possible. It is well known that two machines, having little apparent difference of the wing tips, may behave differently in this respect, the one being comparatively free from tendency to drop a wing, and the other exhibiting this tendency in a marked degree. This suggests that the phenomenon is a critical one, and that small differences in the form of the wing tips may determine whether the behaviour is satisfactory or not. As stated before, it is now thought that the unsatisfactory machine is one where the wing tips are liable to asymmetric stalling, during which one tip suffers a comparatively sudden lift change while the other tip does not. It therefore seems likely that the thing to avoid is a wing tip section that has a *sudden* stall.

This idea led me to exhibit the nature of the stall of the 78 aerofoils of N.A.C.A. Report No. 460 in the form of the diagram of Fig. 6. The letter *F* indicates the so-called front stall, in which the breakway of flow occurs suddenly from the front of the wing with a consequent discontinuous drop in the lift. *R* refers to a rear stall in which the breakaway point moves continuously forward from the rear, producing a smooth lift curve with no discontinuity at the stall. Some cases which were difficult to classify in either of the above two groups are marked *D*. It is at once seen that all the normally used tip sections, of say 9 per cent. to 12 per cent. thickness/chord ratio and with normal cambers, lie in the group *F*. It would thus appear that the natural tendencies of wing tip design lead to those sections which are the worst from the point of view of sudden stalling.

The diagram indicates three types of section which have a gentle stall; very thin sections, very thick sections, and those of medium thickness which have a high centre line camber and a far back position of maximum camber. The very thin sections have a low maximum lift, and accordingly stall at a low incidence. Tips made very thin would thus tend to stall early, but even this might not lead to serious wing dropping if their stall was gentle and free from any liability to sudden changes *different on the two wings*. Very thick sections are hardly desirable at the tips, but I once heard of a case in which thickening the tips was said to have been beneficial. There remains the group of medium thickness sections. They have the disadvantage of a higher profile drag than more normal sections of the same thickness, but it would be exceedingly interesting to know whether, in a bad case of wing dropping, the alteration of the tips to such a section over a length of, say, one chord from the tip, would result in a cure.


N.A.C.A. AEROFOIL PROFILES.
F = Front stall.
R = Rear stall.
D = Doubtful.
2706 2709 2712 2715 2718 2721
4706 4709 4712 4715 4718 4721
6706 6709 6712 6715 6718 6721
2606 2609 2612 2615 2618 2621
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6206 6209 6212 6215 6218 6221
0006 0009 0012 0015 0018 0021 0025
E.E.M.

FIG. 6.

Such an experiment must be made in flight, since these stalling phenomena are so susceptible to scale effect that a small scale model test, on the rolling balance for instance, could not be trusted to indicate the full-scale behaviour with certainty. It might well be that a series of such tests would enable us to find a satisfactory tip design without involving too great a sacrifice due to increased profile drag of the tip sections. If this end could be attained it would certainly remove an uncertain feature of design which sometimes gives the designer an unpleasant surprise.

RESEARCH ON FLUTTER.

The present position as regards design precautions against the occurrence of flutter seems to be satisfactory, but we are not sure how long it will remain so. Let me explain. The intensive research, both theoretical and experimental, carried out some years ago, solved the flutter problem as it then existed. The precautionary measures indicated by this research were almost universally adopted and resulted in the present almost complete immunity from flutter troubles. But speeds are still increasing rapidly, and since flutter can be broadly described as a state in which certain aerodynamic forces win in a fight with elastic forces, it cannot be assumed without proof that measures which succeed to-day will also succeed at the speeds of the future.

If speeds are very high, measures such as the mass-balancing of the controls, though they may be theoretically a remedy at all speeds, may not be carried out with sufficient precision to give safety in practice, since the degree of approach to perfect balance necessary is closer as the speed increases. Moreover the theory does not take full account of all the possible details of the motion, but simplifies the mode of oscillation into what are obviously the more important components. It is therefore important to consider whether these limitations are such as to affect the safety of the aeroplane of to-morrow, on the assumption that it will fly considerably faster than the aeroplane of to-day. There are two major difficulties in doing this. One is the absence of enough reliable data on the aerodynamic forces involved during oscillatory motions, especially when these are rapid, and the other is the labour involved in numerical applications of the theory, especially when there are three or more degrees of freedom to be considered. The first of these difficulties is being overcome by experiments now in hand on the determination of flutter derivatives under various frequencies of oscillation. A number of such determinations was made in the original investigation, but only under rather restricted conditions as regards frequency.

A new technique of measurement has since been evolved in which the model is forced to oscillate at a given frequency and with a given amplitude. The force required to produce this oscillation is transmitted to the model through a short piece of nickel tube, and by making use of the magneto-striction effect in nickel, the variations of stress in the tube are converted into variations of electric potential which can be recorded by a cathode ray oscillograph. It is thus possible to obtain a time history of the force during a complete oscillation of the model. It is hoped that results obtained in this way, correlated with attempts to develop the theoretical treatment of the aerodynamics of an oscillating body, will do much to improve the accuracy with which the forces involved during flutter are known. Concurrently with this work, an effort is being made to evolve methods of dealing more expeditiously with the flutter calculations themselves, including an exploration of the possibility of designing special mechanical aids to computation in this and allied problems.

There is, however, a further reason why present flutter theory may prove inadequate in the future. The theory, as it stands to-day, is an application of the classical method of treatment of oscillation problems, and assumes that the forces involved are linear functions of the displacements and velocities. This assumption is not necessarily true. An aerodynamic quantity such as the hinge

moment of an aileron is frequently not a linear function of aileron angle, while friction in the control linkage introduces another kind of non-linearity. It is therefore thought necessary to study the oscillations of dynamic systems obeying non-linear laws, and to see how far the non-linear effects likely to be involved in normal aeroplane design may affect the flutter problem. This is a very difficult piece of work, and involves also the development of methods of approximate solution of types of differential equations which are not amenable to exact analytical solution.

It is impossible to say, in the present state of knowledge, whether or not these new considerations will become of great importance in flutter prevention before speed increases are limited by some other factor, such as compressibility effects on drag, but since a recrudescence of flutter troubles at the speeds now envisaged would be extremely serious, it is well worth while to face the admittedly difficult problems involved in order to attain some degree of certainty on the point. Meanwhile the designer should continue to apply the remedial measures now in force with as much precision as he can, and keep a sharp eye open for any innovations in design which tend to increase the number of degrees of freedom in any possible mode of flutter. In this connection, there is a great attraction, from the flutter point of view, in any developments that may *decrease* the number of degrees of freedom now existing. One obvious such development, which has been much discussed in recent years, is the adoption of irreversible controls. Such a control, applied for example to the aileron, reduces the wing flutter problem to the comparatively simple case of flexure-torsional flutter, with only two degrees of freedom, but it only does so if the irreversible mechanism is perfect and free from backlash. Herein lies the greatest difficulty of the application of the idea, at any rate to the ailerons, since it has been shown by trial in flight that irreversible ailerons are not in any way undesirable from the point of view of control of the machine. Whether the same conclusion would apply to an irreversible control of the rudder or elevators is not yet known, but it is fairly certain that the successful development of a really good mechanical device for the purpose would lead to its extensive trial, and might go far in the end towards the simplification of design against flutter dangers.

I realise all too well that in this lecture I have omitted many things that could legitimately have been included under its title, and I can only say that the field of aerodynamic research is now so wide that one must needs concentrate on a few major researches, even if these are only treated in broad outline. I shall have succeeded in my task if the remarks I have made on such researches has enabled you to understand more clearly the objects we have in view in carrying them out, or has suggested some new line of thought to you on important problems of aerodynamic design.

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(3) "Effect of Surface Roughness on Characteristics of Aerofoils N.A.C.A. 0012 and R.A.F. 34." R. Jones and D. H. Williams. R. & M. 1708.
(4) "Longitudinal Stability with Elevators Fixed and Free." H. B. Irving. "Flight," October 28th, 1937.

Discussion.

Dr. N. A. V. Piercy (*Fellow*): Not only was the paper valuable and interesting to both theory and practice; it was also very timely. The flat plate check carried out in the C.A.T. established confidence in the methods of measurement employed and its complete success added appreciably to general knowledge. He would raise one or two questions on which Mr. Relf might be prepared to hazard

provisional opinions, such as he might hesitate to include in the body of the paper.

No doubt everyone interested in aeronautics had made calculations from time to time concerning the speeds that would be attained by aeroplanes if they were exposed to skin friction and induced drag alone, apart from one or two minor and unavoidable sources of waste. He imagined that, great as had been the improvement stimulated by Professor Melvill Jones' papers of eight or nine years ago, an increase of actual speeds by 30-50 m.p.h. would fairly represent present results. Some designers had worked on the following lines when unable to base estimates on prior craft of similar type; scale effect was reckoned on skin friction only, leading usually to conservative predictions. They now knew that in this process too far forward a position had been assumed for breakaway in free flight. If correction were made on this score, would predictions still be well upon the safe side? Could Mr. Relf argue in this way whether form drag really remained constant—from a Reynolds number of 1,000,000, say—or whether decrease in passage to full scale could confidently be expected?

Dr. Piercy's idea was that the form drag of a clean aeroplane decreased, but not very much. If that were so, was it possible to foresee a corrective factor in Professor Jones' valuable criterion of efficiency? Could it be said that inasmuch as in this imperfect world, wings and bodies must have thickness, and form drag therefore arise, the maximum efficiency attainable would be, say, 80 or 90 per cent. of Professor Jones' gauge? It seemed a pity to refer to an aeroplane as being only 65 per cent. efficient when only two-dimensional passengers—in the sense of flat plate passengers—could produce 100 per cent.

With regard to Mr. Relf's suggestion that there would soon be a theory of form drag, did he mean an empirical theory based upon analysis of experiments, or a mathematical theory? The former would be of great value. But the possibility of the latter seemed remote and he (the speaker) would like to be corrected if this were not so.

Commenting upon the statement in the paper that with increased wing loadings—and presumably the author was thinking of loadings of 35-40lb. per sq. ft.—lateral stability would be more difficult of attainment, did this imply that lateral stability would be inherently more difficult to attain, in the sense that increase of wing loading might be forbidden on this score, or did it mean no more than that greater accuracy would be required in designing for stability?

Mr. RELF: They did not know yet what would happen to form drag in its variation with Reynolds number; but he suspected it would be found that form drag was roughly proportional to the skin friction coefficient. As to the theory of form drag which would be developed, he said that Mr. Squires was better able than he to discuss that, but he believed it would be semi-empirical in the sense that all turbulent boundary layer theory was semi-empirical, but only to that extent. It looked as though they would arrive at a definite connection between the distribution of skin friction in the boundary layer and the form drag, so that to that extent it would be a real theory.

The reference in the paper to the effect of increased wing loadings upon lateral stability really meant that, as wing loadings increased, the margin of stability became smaller. There was the spiral instability on the one hand, and the oscillatory on the other, the former resulting from too much fin area and the latter from too little. The margin was considerable for low loadings, but was smaller for high loadings. Whether or not a point could be reached at which the margin vanished he was not prepared to say at the moment; but the margin became smaller for high loadings, so that more precision was called for, and they would not be able to achieve that precision without more detailed data than are as yet available. They could not even achieve precision under present conditions; very often fin areas had to be modified because the lateral stability had not been hit off just right.

Mr. H. B. SQUIRE (*Associate Fellow*): With regard to the question as to whether the theory of form drag was semi-empirical, those who were dealing with it were not starting from experimental results and analysing them as far as possible to give relationships between the various quantities, but were starting from the boundary layer equations and solving them, on certain simplifying hypotheses—which he was afraid were unavoidable—to obtain curves giving the profile drag (form drag plus skin friction) for various thicknesses, Reynolds numbers, and transition points. So far as they had been able to check the results against the results of flight tests at the R.A.E., agreement was quite as good as could be expected. There was only one completely satisfactory comparison, and that had shown agreement within one or two per cent.; but too much weight should not be placed upon this until there were other checks available. With regard to the percentage form drag, he believed a rough rule was that for thicknesses up to about 25 per cent. the form drag was the same percentage of the total drag as the thickness was of the chord. However, he hoped that the results of the calculations would be published shortly.

Having compared the drag coefficients shown in Fig. 2 of the paper with the predicted drag, which Mr. Young and he had worked out, he said they appeared to indicate that the transition points were situated about 15 per cent. of the chord from the leading edge. That might be regarded either as an indication of transition point position or a criticism of the theory, but the matter could not be settled until more tests had been made. In view of the difficulty of measuring transition points, he asked whether Mr. Relf had considered drag tests with wires attached to the surface, which would fix the transition points, and so eliminate one difficulty. This had been tried in flight tests at the R.A.E., and it seemed to be quite satisfactory.

Finally, he suggested that possibly Professor Taylor's theory of turbulence might be applied to predict the position of the transition points for aerofoil tests in wind tunnels of known turbulence.

Mr. F. J. W. DIGBY (*Associate Fellow*): With reference to Mr. Relf's statement that there was a reluctance to use slots in modern design, he thought it was fairly well established that a tapered monoplane wing with a slot and flap would give a higher lift coefficient than without a slot. In view of the greater speed range thus obtained, would the disadvantage in respect of drag arising from the use of the slot outweigh the advantages? As far as he knew, tests at full scale, with or without slots, had shown that there was very little difference in drag due to the presence of the slot, but he asked whether Mr. Relf knew if wind tunnel or other tests had been done on the matter.

Mr. RELF: In reply to Mr. Squire, he had not experimented with wires to fix the transition point, but it would be quite a good idea to use wires with some aerofoils in the compressed air tunnel and assume that they fixed the transition. It must be already well forward, and he doubted that it could be made to go much further forward by means of wires. He believed the technique was available for measuring the position of transition. A method had been tried in an ordinary wind tunnel, and it seemed that it should work well in a compressed air tunnel; he proposed to try it. The suggestion that something analogous to Professor Taylor's treatment of the effect of turbulence on sphere drag might be attained for aerofoil drag was important, but he did not feel equal to it, any more than Mr. Squire apparently did. He hoped that Professor Taylor might consider the problem. There was some indication that something of a similar kind was happening—though that remark must not be taken too much to heart because the work had not been carried very far—but pitot-traverse measurements of drag had been made on aerofoils of different chord in the compressed air tunnel, and they did not agree exactly at the same Reynolds number, suggesting that an effect due to scale of turbulence was present. He could not answer Mr. Digby's question concerning the use of the slot on the tapered monoplane wing in respect of drag and lift; it was a matter on which difficult design com-

promise had to be made. Both the effects were comparatively small, but he imagined that on the whole the advantage of the tip slot, due to the extra lift obtained, would more than make up for the disadvantage in respect of drag, provided that a really well fitting slot could be made. However, he did not think there could be very much in it either way. He believed the main objection to the tip slot was simply that it involved the use of more moving mechanical parts than were really needed; the desire was to keep the structure at the wing tip as simple as possible.

Mr. J. LOVE: With reference to the author's curves showing the drag coefficients of complete civil aeroplanes, he asked what was the Reynolds numbers on which the tests were based, that is, whether this was based on the wing chord or the fuselage length?

In some tests he had made some time ago on a somewhat similar arrangement, he said, he had gradually pulled the model to pieces and had subtracted the drag coefficients for each series of tests, the tests being made at the same Reynolds numbers precisely, and had then arrived at curves showing the reduction of drag coefficient for each component at the Reynolds number of that particular component. He had applied the drag coefficient derived from the reduction of drag due to taking off the tail plane for example, to the Reynolds number of the tail plane, based on the chord of the tailplane. Unfortunately, however, the balances he had used were not too accurate, and for very small components he could not get any correlation of curves. But for the wing and fuselage he had managed to get two curves which agreed very well with the skin friction curve. He asked whether work of that nature had been carried out at the National Physical Laboratory.

Mr. RELF: The Reynolds number was based on the wing chord in all the experiments referred to. In those circumstances some curious results were obtained. Using a model with a long body, it was found that the adding of the body to the wing reduced the drag coefficient, because its Reynolds number was greater than that of the wing.

On occasions he had analysed some of the models by taking off the nacelles and tailplane and body separately; but he was not in a position to quote straight away the summation of the drags in relation to the total measured effect of them altogether. Presumably, the result of all that work would be published at some time, but inasmuch as it related to new machines now in course of construction, it could not be published yet.

Mr. R. HADEKEL: The curves showed that the calculated profile drag of the aerofoils was very appreciably above the drag of the flat plate, and he asked why that should be so.

Mr. RELF: The average speed of flow of air over the surface of an aerofoil of finite thickness was higher than the forward speed of the aerofoil; the air passing a thickened aerofoil was accelerated over the front part, and the average speed just outside the boundary layer was higher than the forward speed, and for that reason the skin friction was higher than it would be on a flat plate with the transition point at the same place as on the aerofoil.

Mr. J. A. C. MANSON: With reference to the author's suggestion that, by the choice of a suitable aerofoil from the large and happy family in Fig. 6, it might be possible to make the lateral stability at the stall somewhat better, he asked whether that improvement would extend to the behaviour in a spin and recovery from a spin, or whether the conditions in spinning were too coarse in incidence for any beneficial effect to be felt.

Mr. RELF: The conditions in the spin were of such large incidences that there would not be any appreciable difference in the results obtained with the different sections. But it was known that quite small changes of wing tip design definitely made big differences in wing dropping tendencies, so that if suitable, wing tip shapes and sections could be discovered, it might be possible to eliminate wing dropping altogether.

Mr. W. S. FARREN (*Fellow and Member*) : Commenting on Mr. Relf's reference to the effective Reynolds number, he said that in the report of the discussion on Professor Jones's Wright lecture in New York in December, which he had only just received, was an interesting remark by Mr. Jacobs of Langley Field. Mr. Jacobs made it clear that the conception of an effective Reynolds number, as a rational and reliable scheme of analysis and prediction, was based on the assumption that, at the high Reynolds numbers of full scale flight, the boundary layer was turbulent over practically the whole surface.

The same idea had been apparent in what Professor Betz had said in his paper before the Lilienthal Gesellschaft in Munich in October. Professor Betz showed a diagram, similar to those with which Mr. Relf had illustrated his own paper, of the variation of the drag of a particular aerofoil—rather a thin one—with Reynolds number. The drag passed through a " transition " stage at moderate Reynolds numbers, and then practically coincided with the " turbulent flat plate " curve. Professor Betz deduced that in practice, on the full scale, they were unlikely to be troubled by transition.

He (Mr. Farren) felt that it had now to be recognised that the study of the transition phenomenon was of great practical importance in relation to the drag of streamline aeroplanes. This country was sometimes criticised for being behindhand in its contributions to advance in aeronautics, but here he felt we could fairly claim to have led the way.

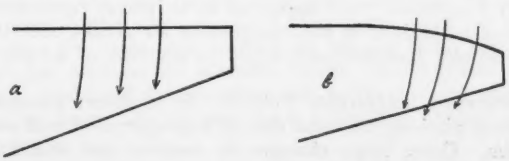
It was interesting to note that the first reference to transition as a major influence on the drag of shapes of practical interest (*i.e.*, apart from flat plates) was in an earlier lecture of Professor Jones's before the Society—his " streamline aeroplane " paper. Professor Jones had there pointed out that the apparently irreconcilable results of the " international tests " of airship models could be explained in terms of transition from laminar to turbulent flow in the boundary layer, and had used them as an important step in his main argument.

Mr. P. NAZIR (*Associate Fellow*) : Commenting upon the suggestion that alteration of the wing tip shapes might prevent the dropping of the wings, he asked whether wing dropping could be cured by merely altering the tip shape. He further asked as to whether such tip alterations, even if they were possible, would interfere with high speed of the aircraft, which he thought would be the case.

He pointed out that there were very few ways of preventing wing dropping, as far as he knew, without affecting the top speed, as appeared from his experiments.

Mr. RELF: It had not yet been proved that wing drop could be eliminated by altering the tip shape only; the rest of the wing might enter into the problem to some extent. He had hopes, however, that means would be found of preventing wing drop by shaping the tips and without any great sacrifice in respect of increased drag. But that was merely a pious hope.

Mr. W. E. GRAY: The results of some tests he had made about a year ago on a tapered wing in a tapered tunnel might help towards the realisation of the pious hope which Mr. Relf had expressed. Using a tunnel of trapezium cross-section of ratio 2/1, he had placed a wing right across it of 2/1 taper. That was a piece of trickery in order to get an infinite aspect ratio effect on a tapered wing. In plan he had found that the taper produced a bending of the flow—outward on the under-surface, and inward over the upper surface as shown in sketch (*a*)—which



was not merely a surface flow. Since taper produced that bending, it seemed that if the taper ratio were increased near the tip, as in sketch (*b*) the bending could be progressively increased in that region so as to give a convergent region of flow as shown. In other words, the suction region along the leading edge was drawing the air in a converging manner over the area where there was usually trouble through the tip stalling. The tip would thus approach an elliptical one. That might help, though it was not nice from the constructional point of view.

Mr. RELF: Span-wise components of air flow had been found in experiments on tapered wings at N.P.L., and that the plan form as well as the shape of the tip sections certainly had an influence on the wing dropping problem. Tests on a wing of elliptic plan form and constant section showed that it tended to stall all along at once, as one would expect from theory.

Mr. G. B. FENTON (*Associate Fellow*): He asked for an expression of opinion with regard to thick wings of about 25 per cent. of the chord. Most people were becoming interested in wings of such thickness, and judging by curves shown and by the experiments carried out in the C.A.T., he believed they could put up with the increased drag by reason of the other advantages arising from the increased wing thickness; the increased drag was certainly there, but the advantages of extra wing thickness probably balanced that disadvantage. He also asked whether the experimental work on the effect of compressibility on those thick wings was keeping in line with the Reynolds number effect, as it were, because the two things must be bound up together. Reports had been published which gave tentatively a figure of about 4 per cent. increase in profile drag on the 25 per cent. thickness wing at a speed of 300 m.p.h., and the increase was considerably more at 370 m.p.h. That was very important, and surely the two different lines of research must proceed hand in hand if they were really to find out whether thick wings could be used on high speed aeroplanes.

Commenting on the family of 78 related aerofoils in Fig. 6., he said there was another report (No. 610) on some American related aerofoils, with the camber point put forward. The characteristics were very thoroughly analysed in that very comprehensive report, and he asked whether Mr. Relf had studied it and whether he could express an opinion on it; in other words, could they trust it? One of the reasons he asked was that in the report the maximum lift coefficient with an effective Reynolds number of 8×10^6 was given as 1.84 for a 4 per cent. camber wing, and as 1.74 for a 2 per cent. camber wing. Those figures seemed very high, and surely the value of the report would suffer if those coefficients were not really as high as they were stated to be.

Mr. RELF: He had not referred to compressibility effects and drag in his paper because Mr. Lock had dealt with that subject, so far as it had been explored at the National Physical Laboratory, in a recent lecture to the Society. But he believed Mr. Fenton was right, that if the extra drag of the thick sections could be accepted, the first factor that would militate against the use of such sections would be the compressibility effect, as speeds became higher, because the compressibility effect was known to be greater on thick wings than thin wings. He could not, however, add anything to the statements made in the paper by Mr. Lock, because no further tests had been made.

With regard to the American report, he said that the maximum lifts of all medium thickness sections tested in the American tunnel were definitely too high at the Reynolds number of test (3.5 millions), because the tunnel was very turbulent, but if they were related to what the Americans call the effective Reynolds number of about 8 millions, they appeared to be about right and fitted in fairly well with the results obtained in the compressed air tunnel over the whole range. This conclusion would, however, not apply to sections of 20 per cent. thickness and over.

Mr. R. S. STAFFORD (*Associate Fellow*): It is rather sweeping to say that the change in wing pitching moment due to flap operation was roughly the same for all aeroplanes. Quite large changes in moment are found as between one

plan form and another. Thus, for a tapered wing with a straight leading edge, the change of pitching moment was much more negative than for a similar wing with straight trailing edge when the flaps are lowered at the centre; the difference in moment change may be of the order of 30 per cent. With very strong sweep-back it is possible to eliminate entirely the change of pitching moment due to flap operation, as in the case of a flapped tail-less aeroplane.

Mr. RELF: He did not mean to suggest that there was no change at all in the pitching moment of the wing due to flaps. He had suggested that the changes were not large compared with the difference in contribution of the tail to the pitching moment in the case of a machine with the C.G. right forward and a machine in which the C.G. was right back. He agreed that it must depend on the sweep-back to some extent, but there were not very big variations except in designs of extreme sweep-back. To secure sufficient sweep-back to eliminate the effect altogether one would have to provide almost as much as in the case of Professor Hill's pterodactyl, and one would not like that for other reasons.

Mr. DE PARAVICINI (*Associate Fellow*): With reference to the smoothness necessary in aerofoil surfaces, he asked if there was any difference in the drag when using a paint with a particle size of about one-thousandth inch and a paint having a particle size of about four or five-thousandths inch. The curves which Mr. Relf had shown seemed to indicate that the drag coefficient was almost constant for all rough surfaces and did not fall off with increasing Reynolds number. It might be possible to produce rather a good aeroplane for engine performance test work if one could be certain that the drag would remain constant. He asked if there were any ideal drag that could be aimed at for a rough matt surface aeroplane compared with the ideal flat plate smooth skin friction drag that had been discussed in the paper.

Mr. RELF: There was a certain degree of roughness which produced no effect at all; above that, the drag began to increase, and the greater the roughness became, the lower was the Reynolds number at which the increase of drag commenced. So that it was not necessary to have a surface absolutely polished, but a greater degree of smoothness was necessary as the Reynolds number was increased. Therefore, it ought to be possible to arrive at a matt surface (*i.e.*, a surface that would not reflect light regularly) which was aerodynamically smooth because the roughness permissible even at the larger Reynolds number was of the order of five-thousandths inch, whereas the wave-length of light was one-fifty-thousandth of an inch. It was quite possible that a surface with a definite roughness would be useful in an aeroplane for test purposes, in which it was desired to avoid drag changes such as may be produced by slight deterioration of a smooth surface. There was no definite ideal value for a rough surface, analogous to that for the smooth flat plate, since the drag depends on the size, shape, and distribution of the excrescences forming the roughness.

Mr. R. A. SHAW (*Associate Fellow*): He asked what evidence there was of the effect on profile drag of the shape of the wing trailing edge, whether it was best in the form of a knife edge or simply radiused. He suggested that there might even be an advantage in some respects from making the trailing edge of the wing a little concave.

Mr. RELF: He had some ideas about this, but no definite knowledge; in other words, he had not carried out the experiment, but he had a feeling that the slight rounding of the trailing edge did not increase the drag at all, or increased it very little indeed. The flow behind a cylinder contained periodic eddies. But if the cylinder formed the after-end of a long body, such as a wing, the flow did not break off in the same way, in fact, he did not think that a periodic eddy-shedding, as in the well-known Kàrmàn street, would occur. That was, he thought, why one could use a finite thickness at the trailing edge without losing much in respect of drag. He did not think a concave trailing edge would affect the behaviour at all.

Mr. H. DAVIES (*Associate Fellow*): With reference to surface roughness, he asked for some general guidance as to the area of the wing which should be kept perfectly clear of excrescences such as rivet heads, what the effect of such obstructions would be in the back area towards the trailing edge, and what their relative effect would be on the top and bottom surfaces of the wings.

Mr. RELF: To achieve minimum drag it was necessary to keep the surface smooth all over. In one experiment the whole surface of one aerofoil was roughened, and the back half only in another, and it was found that the roughening of the back half accounted for one-third of the whole drag increase, so that obviously the back half was important. But he suggested that much was to be learned from the information published in the R and M's on that subject, and that further valuable information would be published in a further report from the R.A.E. on the results of measuring in flight the effects of rivet heads on different parts of the wing. There was no reason to suppose that the effect of roughness was widely different on the upper and lower surfaces, but he knew of no specific experiments on this point.

Mr. J. E. SERBY: It was thought that flush riveting would be very valuable from the point of view of reducing drag, but he pointed out that the maximum advantage would not be derived from it unless care were taken to ensure that the indentations in the riveting did not cause the transition point to move forward. He was convinced that they would pull the transition point forward to 5 or 10 per cent. from the leading edge unless the indentations were filled and polished back to about 20 per cent. behind the leading edge.

With regard to the 25 per cent. thick wing, he said that on the Hawcon used for these tests at Farnborough they had tested wing sections 14 per cent. and 25 per cent. thick. Using the momentum method the profile drags of these sections were found to be 0.0065 and 0.0080 when the metal covered sections were polished carefully. Mr. Young had calculated what the drag coefficients would be if the transitions had gone forward to 15 per cent. of the chord behind the leading edge, and the figures he arrived at were respectively 0.0080 and 0.0106. It was felt that it should be possible for designers even now to make the leading edges of wings so smooth that the transition could be kept back to 15 per cent. aft of the leading edge.

The drag values he had mentioned showed a difference of 0.0026 between 14 per cent. and 25 per cent. which was rather more than 10 per cent. of the drag of the whole aeroplane. If one chose to build an aeroplane with wings 25 per cent. thick at the root, the tips would be something like 12 per cent. in thickness, so that it would suffer a drag increase of perhaps one-third or one-half the amount he had mentioned, and that might increase the drag of the whole aeroplane by 3 or 5 per cent., representing a speed decrease of 1 or 2 per cent., which seemed very little to pay for having a wing in which the root depth was one-quarter of the chord length. It must be remembered that the drag of sections inside the slipstream would be higher than the above figures, but the difference due to thickness would still be appreciable.

Encouraged by these results, they were having built for test at Farnborough on the Hawcon a wing 30 per cent. thick at the root, tapering to 15 per cent. at the tip, and he was reasonably hopeful that its performance would be quite good. The filleting of the 30 per cent. wing would be awkward, and it might be necessary to experiment before they could get it right. It was hoped to explore that by the momentum method.

Apropos of wing dropping, on which tests were proceeding, it was proposed to make up four different sets of wings to test on two different aeroplanes which would be almost identical except that one would have a 4/1 taper and the other a 2/1 taper; so that it was hoped to deal with the taper factor as well. The tests would cover differences of camber and differences in the position of the maximum camber as well as differences in actual wing section thickness. It was hoped to explore, on the standard taper aeroplane, some of the sections which, they

were beginning to think, were notorious wing-droppers, and it was hoped to improve them.

Mr. SMETT: He asked whether there was evidence of wing-drop being due to a front stalled tip.

Mr. RELF: There was. Wing-dropping was more likely to happen in a case where the lift curve showed a sudden drop, corresponding with a front stall, because under those conditions one tip might stall suddenly while the other did not. In a case where the lift curve was perfectly smooth and fairly flat at the stall it might not matter whether or not the tips were stalled; there might not be sudden fluctuations of rolling moment. It seemed more rational to expect good behaviour where there was a continuous lift curve than where it was discontinuous. There was no more in it than that.

At the conclusion of the discussion a hearty vote of thanks was accorded Mr. Relf for his paper.

THE ELASTIC STABILITY OF A CURVED PLATE UNDER AXIAL THRUSTS.

By S. C. Redshaw, Ph.D., M.Sc., Assoc.M.Inst.C.E., A.F.R.Ae.S.

I. Summary.

Theoretical critical stresses have been obtained for four cases in each of which a curved panel has been subjected to a compressive stress, parallel in direction to a generator and uniformly distributed around its top and bottom circumferential edges.

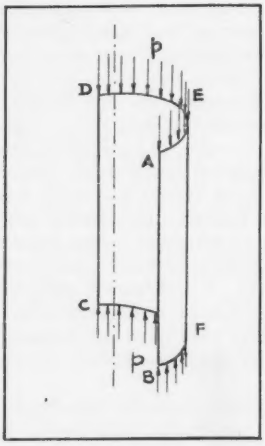


Fig. 1.

In each case the critical stress may be expressed by an equation of the form

$$p = \{ \pi^2 t^2 / 12 (1 - \sigma^2) b^2 \} EK$$

where K is a coefficient which may be split into two parts, K_F and K_C, where these are flat and curved plate coefficients respectively.

Then

$$K = K_F + K_C$$

and if the curvature of the plate is zero, the value of the critical stress obtained will be the flat plate value as obtained by other investigators.

Both coefficients are dependent on the ratio a/nb, that is to say, the ratio axial length of plate *divided by the product* of the circumferential length of plate and the number of half waves in the axial direction.

In addition the curved plate coefficient is dependent on the curvature of the plates which has a most marked effect on its numerical value.

In all the cases the minimum critical stress is obtained when the coefficient K is a minimum. For this condition to be satisfied a particular value for a/nb must be found for each value of the bulge thickness ratio d/t. That is to say, if we have a definite value for a/b the panel will tend to buckle, as nearly as possible, into a number of half waves n which will make the value a/nb agree with the minimum value.

The various edge conditions and expressions for the critical stresses may be summarised in the following table:—

Case	Condition of Fixing of Edge.				Value of K_{min} in expression for critical stress $p_{min} = \{ \pi^2 t^2 / 12 (1-\sigma^2) b^2 \} E K_{min}$
	AED	BFC	AB	DC	
a	Simply supported	Simply supported	Simply supported	Simply supported	$4 + (192/\pi^4)(1-\sigma^2)(d^2/t^2)$, for $d/t \leq 1.471$ N.B.—$p_{min} = [1/\{3(1-\sigma^2)\}]^{\frac{1}{2}} Et/r$ for $d/t \geq 1.471$
b	Simply supported	Simply supported	Fixed	Fixed	$2\{(16/3 + 768\, d^2/\pi^4 t^2)^{\frac{1}{2}} + 1\}$
c	Simply supported	Simply supported	Simply supported	Free	$(2/\pi^2)\{16\, d\sqrt{3}/t + 3(1-\sigma)\}$
d	Simply supported	Simply supported	Fixed	Free	$(1/\pi^2)\{2(162/13 + 768\, d^2/t^2)^{\frac{1}{2}} + 135(6-7\sigma)/91\}$

With increasing values of the bulge thickness ratio d/t the expression for the critical stress for cases (*b*), (*c*) and (*d*) approaches the value

$$p = (\sqrt{3}/3)\, E\, (t/r)$$

which agrees very closely with the established result for the complete cylinder. When $d/t = 2.0$ the error involved in using the above formula does not exceed 2 per cent.

Experimental data have been obtained by other investigators for cases (*a*) and (*b*). In both cases the experimental values may be as low as 40-50 per cent. of the theoretical values.

II. Introduction.

During recent years there has been a great increase in the use of light metal alloy sheets for the covering of aircraft structures.

A need for economy in weight and space has made it necessary that the metal covering should not only serve as the external cover for the structure, but should be considered as an integral part of the frame capable of being stressed. In the popular semi-monocoque form of construction the structure consists of a thin metal tubular shell reinforced at intervals with radial hoops and longitudinal stiffeners.

In this manner the shell is divided into flat or curved plates and its strength depends on their strength together with the strength of the plate stiffening members.

The thickness of the plate used is small when compared with its length and breadth and as a result failure of the whole structure may be caused by the instability of one of the flat or curved plate components.

A plate may show signs of instability by the formation of waves when a certain critical load has been applied, disappearing entirely on the removal of the load and leaving the structure undamaged. This form of elastic instability, although not necessarily leading to the collapse of the structure as a whole, is undesirable and it is advisable to know the approximate critical stress for the plate of the dimensions to be incorporated in the structure.

The stability of flat plates under axial thrusts has been considered by several investigators, but the problem of the curved panel apart from the complete tube, has received very little attention.

In the present paper the writer has considered one aspect of the curved plate problem, that in which the plate is subjected to an axial thrust uniformly

distributed along its curved edges, four forms of axial edge support being considered.

III. Notation.

x, y, z, rectangular co-ordinates.
r, radius of curvature.
θ, angle of arc.
a, length of plate parallel to a generator.
b, circumferential width of plate.
ϕ, angle subtended by arc of length b.
α, strain in middle surface in direction of x.
β, circumferential strain in middle surface.
c, shear strain in middle surface.
τ, twist per unit length.
τ_0, initial twist.
c_1, c_2, changes of curvature.
u, axial displacement.
η, circumferential displacement.
w, radial displacement.
n, m, number of half wave lengths of buckled panel in axial and circumferential directions respectively.
$2h = t$, thickness of plate.
$I = 2h^3/3$, moment of inertia of plate.
σ, Poisson's ratio.
$E = (1-\sigma^2)E'$, modulus of elasticity.
$C = Et^3/\{12(1-\sigma^2)\}$, flexural rigidity of plate.
p, stress
$f = h^2/3r^2$, a factor.
W, work done by external forces.
V', strain energy of internal forces.
V, total strain energy.
$d = b^2/8r$, bulge of a curved panel.
$Q = a/nb$, a factor.
$k = n\pi r/a$, a factor.
$q = m\pi/\phi$, a factor.
K_F, critical stress coefficient for flat plate.
K, critical stress coefficient for curved plate.
K_C, critical stress coefficient depending on curvature of plate.

IV. The General Problem.

In estimating the critical buckling load for a flat plate it is usual to assume that the bending of the plate is such that its middle plane is not stretched. Accordingly an inextensional form of deformation is assumed as only the bending energy and the work done by the external forces acting in the middle plane of the plate are considered.

It is possible to consider the stability of the curved plate either by an inextensional method or by considering a deformation of the middle plane.

The theory of inextensional deformation of shells, due to Lord Rayleigh (1) was used by him in the solution of problems connected with rings and shells; he observed that the displacements due to the extension of the centre line of a thin ring is small compared with the displacement due to bending, and in most cases could be neglected. By using this approximation the solution of his problems was greatly simplified.

If the inextensional method were applied to the case of the curved plate certain conditions would have to be satisfied, namely:—

(*a*) There must be no strain in the middle plane along an axis parallel to the generator of the plate.

(*b*) There must be no circumferential strain in the middle surface.

(*c*) There must be no shearing strain in the middle surface.

These conditions are satisfied if:—

$$\alpha = \partial u/\partial x = 0$$
$$\beta = w/r + \partial\eta/\partial\theta = 0$$
$$c = r\,(\partial\eta/\partial x) + (1/r)\,(\partial u/\partial\theta) = 0 \quad . \quad . \quad . \quad . \quad (1)$$

where α = strain in middle surface in direction of x.

β = circumferential strain in middle surface.

c = shear strain in middle surface.

u, η, w = axial, circumferential and radial displacements, respectively, from an equilibrium position.

If the displacement equations were carefully chosen these equations could be satisfied, at the same time care would have to be taken to ensure that the boundary conditions were fulfilled.

If, however, a deformation of the middle plane is allowed, the strain energy due to the stretching of the middle plane must be considered. This second method is more general and providing a solution can be obtained by its use, it is preferable.

In all the cases of the curved plate, considered by the writer, the stretching of the middle surface has been taken into account.

Using the extensional method the strain energy of a deformed shell is composed of:—

(*a*) The strain energy due to bending.

(*b*) The strain energy due to the extension of the middle surface.

With the notation enumerated at the commencement of this section we can express these energies as (2, 4):—

$$\text{Bending energy} = \tfrac{1}{2} E'I \{ c_1^2 + c_2^2 + 2\sigma c_1 c_2 + 2(1-\sigma)(\tau-\tau_0)^2 \} \quad . \quad (2)$$

$$\text{Extension energy} = E'h \{ \alpha^2 + \beta^2 + 2\sigma\alpha\beta + \tfrac{1}{2}(1-\sigma)c^2 \} \quad . \quad (3)$$

Therefore the total energy per unit area of a curved plate will be

$$V' = E'h \{ \alpha^2 + \beta^2 + 2\alpha\beta + \tfrac{1}{2}(1-\sigma)c^2 \}$$
$$+ \tfrac{1}{2} E'I \{ c_1^2 + c_2^2 + 2\sigma c_1 c_2 + 2(1-\sigma)(\tau-\tau_0)^2 \} \quad . \quad . \quad (4)$$

The cases considered in this work have been solved by the minimum energy method, which is an extension of Lord Rayleigh's principle. The value of the critical stress given by this method will be approximate; but the approximation is usually so close to the value obtained by more rigorous methods that it can be used with confidence.

In applying the method the plate is assumed to be loaded by forces acting in its middle plane and a form of displacement of the plate consistent with the boundary conditions and involving arbitrary constants is assumed. The critical load will be obtained when the strain energy of the plate is equal to the work done by the external forces on the plate during the buckling.

It will be observed that a certain possible deformation is chosen and in consequence we have conditions of stability which are necessary but need not be sufficient.

The difficulty in the application of the method is the choice of the possible deformation.

By assuming a form of deflection curve we always obtain a value for the critical load higher than the correct value, because the true curve corresponds to the curve of least resistance of the plate. However, providing the boundary conditions are satisfied and that the deflection curve is of a reasonable form, the results obtained are sufficiently accurate for most engineering purposes (3).

V. The Application of the Minimum Energy Method to the Curved Plate.

The plate $ABCD$ (see Fig. 2) may be considered as being a portion of a cylinder of length a and radius r.

Let the arc to be considered subtend an angle ϕ at the centre. Various conditions of support will be considered for the axial edges AB and CD and the circumferential edges AED and BFC.

In each case the edges AED and BFC are subjected to a uniform pressure p.

Take cylindrical-polar co-ordinates about the x axis and let the position of a particle in the middle surface when the panel is unstrained by (x, r, θ) and let its position in the strained state be

$$(x+u_0+u,\ \theta+\eta,\ r+w_0+w)$$

where u_0 and w_0 are the displacements in an equilibrium position and so for the purpose of calculating the gain in strain energy, when the plate displaced from this position we can neglect u_0 and w_0 and take the displacements as (u, η, w).

Let the compressive stress in the plate be p and the thickness of the plate $2h$.

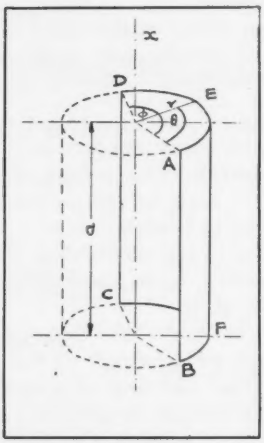


Fig. 2.

In order to find the loss in potential energy of the external forces during the deformation it is necessary to determine by how much the plate contracts in consequence of the strains; this contraction may be expressed as

$$\delta a = \{ \partial u/\partial x + \tfrac{1}{2} r^2 (\partial \eta/\partial x)^2 + \tfrac{1}{2} (\partial w/\partial x)^2 \} \delta x \quad . \quad . \quad (5)$$

then the work done by the pressure p on a panel of the length a, arc ϕ and thickness $2h$ will be

$$W = 2hp \int_0^{\phi} \int_0^{a} \{ \partial u/\partial x + \tfrac{1}{2} r^2 (\partial \eta/\partial x)^2 + \tfrac{1}{2} (\partial w/\partial x)^2 \} dx r d\theta \quad . \quad (6)$$

Then the total potential energy of the internal and external forces is given by

$$V = \int_0^{\phi} \int_0^{a} V' dx r d\theta - W \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The plate will be unstable if

$$W > V' \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and the critical value for the compressive stress will be found when the total potential energy of the system is a minimum.

Let c_1, c_2 = change of curvature.
τ = twist per unit length.
τ_0 = initial twist.

Then

$$\begin{aligned}
&\alpha = \partial u/\partial x \\
&\beta = w/r + \partial \eta/\partial \theta \\
&c = r\,\partial \eta/\partial x + (1/r)\,\partial u/\partial \theta \\
&c_1 = \partial^2 w/\partial x^2 \\
&c_2 = (1/r^2)\,(w + \partial^2 w/\partial \theta^2) \\
&\tau = (1/r)\,(\partial^2 w/\partial x \partial \theta) - \partial \eta/\partial x \\
&\tau_0 = 0 \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)
\end{aligned}$$

In the above relationships the displacements in an equilibrium position have been omitted as they are not necessary for our purpose.

Using the above values equation (4) becomes

$$\begin{aligned}
V' = E'h\,\{\,&(\partial u/\partial x)^2 + (w/r + \partial \eta/\partial \theta)^2 + 2\,\sigma\,(\partial u/\partial x)\,(w/r + \partial \eta/\partial \theta) \\
&+ \tfrac{1}{2}\,(1-\sigma)\,[r\partial \eta/\partial x + (1/r)\,\partial u/\partial \theta]^2\,\} \\
&+ \tfrac{1}{2}\,E'I\,\{\,(\partial^2 w/\partial x^2)^2 + (1/r^4)\,(w + \partial^2 w/\partial \theta^2)^2 \\
&+ (2\,\sigma/r^2)\,(\partial^2 w/\partial x^2)\,(w + \partial^2 w/\partial \theta^2) + 2\,(1-\sigma)\,[(1/r)\,(\partial^2 w/\partial x \partial \theta) - \partial \eta/\partial x]^2\,\} \qquad (10)
\end{aligned}$$

Then

$$V = \int_0^b \int_0^a V' dx r d\theta - 2\,hp \int_0^\phi \int_0^a \{\,\partial u/\partial x + \tfrac{1}{2}\,(r^2)\,(\partial \eta/\partial x)^2 + \tfrac{1}{2}\,(\partial w/\partial x)^2\,\}\,dx r d\theta \qquad (11)$$

The next step is to assume a form for the displacements u, η and w compatible with the boundary conditions and to substitute the various differential coefficients of these displacements in equation (11).

In assuming displacement equations for u, η and w arbitrary constants giving the actual values of the displacements will have to be introduced, although it will not be necessary to determine the magnitudes of these displacements.

When the plate begins to buckle the displacement equations may be expressed in the form

$$\begin{aligned}
&u = A f_1(\theta)\, f_1(x), \\
&\eta = B f_2(\theta)\, f_2(x), \\
&w = C f_3(\theta)\, f_3(x) \qquad . \quad . \quad . \quad . \quad . \quad (12)
\end{aligned}$$

A, B and C being arbitrary constants and the various functions of θ and x being decided upon in a manner which will render the displacements reasonable according to the boundary conditions of the particular case under consideration.

Then for a maximum or minimum value of V:—

$$\partial V/\partial A = 0,\ \partial V/\partial B = 0,\ \partial V/\partial C = 0 \qquad . \quad . \quad . \quad (13)$$

The critical buckling stresses for curved plates with various edge restraints will now be considered.

Case (A). All Edges Simply Supported.

In a previous solution of this case (5) the writer assumed different displacement equations which, although not actually satisfying the boundary conditions at the circumferential edges, could be considered satisfactory in view of the fact that, unless the length of the plate is small in comparison with the radius of curvature, the boundary conditions on the two curved edges have little effect on the critical stress.

Referring to R. and M. 1565, p. 6, the expansion of expression (13) leads to exactly the same results as those given by equations (34) and (42) in the present work.

The writer attempted to simplify the work in R. and M. 1565 by assuming that the tangential displacement was so small that it could be neglected, this assumption is not satisfactory, and as a result the curvature term

in the expression for the critical stress of the panels of small curvature was over estimated.

Timoshenko investigated this case by using a different method and in some cases obtained values for the critical stress about 20 per cent. lower than those obtained by the writer (6). In the present paper the case has been solved by the minimum energy method without ignoring the tangential displacement. The results obtained are essentially the same as those derived by Timoshenko (10).

The boundary conditions for this case will be

$$w=0;\ \partial^2 w/\partial x^2+(\sigma/r^2)(w+\partial^2 w/\partial\theta^2)=0;\ \text{when } x=0 \text{ and } x=a \quad . \qquad (14)$$

$$w=0;\ (1/r^2)(w+\partial^2 w/\partial\theta^2)+\sigma\,\partial^2 w/\partial x^2=0;\ \text{when } \theta=0 \text{ and } \theta=\phi \quad . \qquad (15)$$

If the length and circumferential breadth of the plate contain a whole number of half wave lengths n and m respectively and putting

$$n\pi r/a=k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (16)$$

and

$$m\pi/\phi=g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (17)$$

Then the following displacement equations will satisfy the above boundary conditions :—

$$\left.\begin{aligned} u&=A\sin g\theta\cos(kx/r)\\ r\eta&=B\cos g\theta\sin(kx/r)\\ w&=C\sin g\theta\sin(kx/r) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \qquad (18)$$

Then from equation (6) we have

$$W=2hpr\int_0^{\phi}\int_0^{a}\{-(k/r)A\sin g\theta\sin(kx/r)+(B^2h^2/2r^2)^2\cos^2 g\theta\cos^2(kx/r)$$
$$+(C^2k^2/2r^2)\sin^2 g\theta\cos^2(kx/r)\}\,dx\,d\theta \quad . \quad . \quad . \qquad (19)$$

from which

$$W=(hpak^2\phi/4r)(B^2+C^2) \quad . \quad . \quad . \quad . \qquad (20)$$

providing n is an even or large integer.

From equations (7) and (10)

$$V=(E'h/r)(a\phi/4)\{k^2A^2+C^2-2BCg+B^2g^2-2\sigma kAC$$
$$+2\sigma kABg+\tfrac{1}{2}(1-\sigma)(A^2g^2+2ABkg+B^2k^2)\}$$
$$+(E'Ia\phi/8r^3)\{k^4C^2+C^2(1-g^2)^2-2\sigma C^2k^2(1-g^2)$$
$$+2(1-\sigma)k^2(C^2g^2-2BCg+B^2)\}-(hpak^2\phi/4r)(B^2+C^2) \quad . \qquad (21)$$

For V to have a minimum or maximum value for variations in A, B and C

$$\partial V/\partial A=0,\ \partial V/\partial B=0,\ \partial V/\partial C=0 \quad . \quad . \quad . \qquad (22)$$

this enables three linear homogeneous equations in A, B and C to be formed.

Eliminating A, B and C from these equations we see that the following determinant must be equal to zero :—

$$\begin{vmatrix} 2k^2+(1-\sigma)g^2 & kg(1+\sigma) & -2\sigma k \\ kg(1+\sigma) & 2g^2+(1-\sigma)k^2+4f(1-\sigma)k^2-2pk^2/E' & -2g-4(1-\sigma)k^2gf \\ -2\sigma k & -2g-4(1-\sigma)k^2gf & 2+2f[k^4+(1-g^2)^2-2k^2(\sigma-g^2)]-2pk^2/E' \end{vmatrix}=0$$
$$\quad . \quad . \quad . \quad . \quad . \qquad (23)$$

where

$$f=h^2/3r^2 \quad . \quad . \quad . \quad . \quad . \qquad (24)$$

In expanding this determinant powers and products of p/E' and f, which are both small, may be neglected.

Experimental data show that thin shells normally buckle into short longitudinal waves, therefore n is large and k is large.

Using this approximation determinant (23) gives when expanded

$$p/E' = (f/k^2)\,(k^2+g^2)^2 + k^2\,(1-\sigma^2)/(k^2+g^2)^2 \quad . \quad . \quad . \quad (25)$$

Then using relationships previously stated we have

$$p/E' = (\pi^2 t^2/12\,b^2)\,[(nb/a + am^2/nb)^2 + \{\,(1-\sigma^2)\,12\,\pi b^4/\pi^4 t^2 r^2\,\}\,/(nb/a+am^2/nb)^2] \quad . \quad . \quad . \quad . \quad . \quad (26)$$

It will be convenient to write

$$b^2/8\,r = d \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

$$\therefore\ 12\,b^4/\pi^4 t^2 r^2 = (768/\pi^4)\,(d^2/t^2) \quad . \quad . \quad . \quad . \quad (28)$$

$$\therefore\ p/E' = (\pi^2 t^2/12\,b^2)\,[(nb/a+am^2/nb)^2 + \{\,(1-\sigma^2)\,768\,d^2/\pi^4 t^2\,\}\,/(nb/a+am^2/nb)^2] \quad . \quad . \quad . \quad (29)$$

(Providing ϕ is not large d denotes the " bulge " of the panel, see Fig. 3, $d = r\,(1-\cos\frac{1}{2}\phi)$ or $d = b^2/8\,r$ approximately.)

Put

$$(nb/a+am^2/nb)^2 = T \quad . \quad . \quad . \quad . \quad . \quad (30)$$

Then for p to be a minimum

$$dp/dT = 0 \quad . \quad . \quad . \quad . \quad . \quad (31)$$

which gives

$$T_{\min} = \{\,(768/\pi^4)\,(1-\sigma^2)\,d^2/t^2\,\}^{\frac{1}{2}} \quad . \quad . \quad . \quad (32)$$

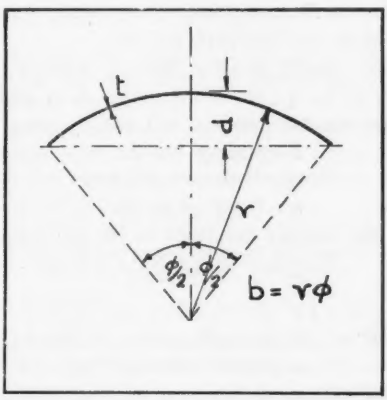


FIG. 3.

Substituting this value into equation (29)

$$p = (\pi^2 t^2/12\,b^2)\,[(96/\pi^2)\,\{\,1/3\,(1-\sigma^2)\,\}^{\frac{1}{2}}\,(d/t)]\,E \quad . \quad . \quad (33)$$

Remembering that $d = b^2/8\,r$ this equation reduces to

$$p = [1/3\,(1-\sigma^2)]^{\frac{1}{2}}\,Et/r \quad . \quad . \quad . \quad . \quad (34)$$

this value for the critical stress agrees exactly with the value obtained by Southwell (7) for axially loaded circular tubes.

For this value to be applicable certain limitations are imposed upon the d/t ratio.

Put

$$Q = a/nb \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

and writing K for the bracketed term in (29) we have:—

$$K = (1/Q+Qm^2)^2 + [(1-\sigma^2)\,(768/\pi^4)\,(d^2/t^2)]/(1/Q+Qm^2)^2 \quad . \quad (36)$$

For p to be a minimum K must be a minimum; this condition is given by

$$dK/dQ = 0 \quad . \quad . \quad . \quad . \quad . \quad (37)$$

Then from (36) and (37)

$$d/t = \{\,(m^2Q^2+1)^2/Q^2\,\}\,(\pi^2/16)\,\{\,1/3\,(1-\sigma^2)\,\}^{\frac{1}{2}} \quad . \quad . \quad (38)$$

For any value of ϕ and m,

$$(m^2Q^2+1)^2/Q^2 \geqq 4 \quad . \quad . \quad . \quad . \quad . \quad (38a)$$

Then if

$$d/t < (\pi^2/4)\,[1/3\,(1-\sigma^2)]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (39)$$

$$i.e.,\ d/t < 1.471\ (\sigma=0.25) \quad . \quad . \quad . \quad . \quad (40)$$

The result given by equation (34) cannot apply and another value must be obtained from equation (29).

The minimum value will be obtained when

$$(m^2Q^2+1)^2/Q^2=4 \quad . \quad . \quad . \quad . \quad . \quad (41)$$

Then substituting this value into equation (29) we have

$$p/E'=(\pi^2t^2/12\,b^2)\,[4+(192/\pi^4)\,(1-\sigma^2)\,(d^2/t^2)] \quad . \quad . \quad (42)$$

This expression should be used if

$$d/t < \pi^2/4\,[1/3\,(1-\sigma^2)]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (43)$$

It will be observed that if $d/t=0$ (29) becomes

$$p/E'=(\pi^2t^2/12\,b^2)\,[nb/a+am^2/nb]^2 \quad . \quad . \quad . \quad (44)$$

which agrees identically with the critical stress obtained for a rectangular plate simply supported at the edges (8).

CASE (B). CIRCUMFERENTIAL EDGES SIMPLY SUPPORTED, AXIAL EDGES CLAMPED.

The boundary conditions for this case will be

$$w=0;\ \partial^2w/\partial x^2+(\sigma/r^2)\,(w+\partial^2w/\partial\theta^2)=0,\ \text{when } x=0 \text{ and } x=a \quad . \quad (45)$$

$$w=0;\ \eta=0;\ \eta+\partial w/\partial\theta=0,\ \text{when } \theta=0 \text{ and } \theta=\phi \quad . \quad . \quad (46)$$

The following displacement equations will satisfy these conditions:—

$$u=A\sin g\theta\cos(kx/r)$$

$$r\eta=B\sin g\theta\sin(kx/r)$$

$$w=C\sin^2 g\theta\sin(kx/r) \quad . \quad . \quad . \quad . \quad (47)$$

Then proceeding in the manner described in the previous section we have

$$W=(hpk^2\phi a/4\,r)\,(B^2+3\,C^2/4) \quad . \quad . \quad . \quad . \quad (48)$$

and

$$(4\,r/E'ha\phi)\,V=\{k^2+\tfrac{1}{2}g^2(1-\sigma)\}A^2+\{g^2+\tfrac{1}{2}k^2(1-\sigma)\}B^2+3\,C^2/4$$
$$+f\{2(1-\sigma)k^2B^2+[3\,k^4/4+4\,g^4+3/4-3/2\,k^2\sigma+2(1-\sigma)k^2g^2]\,C^2\}$$
$$-(pk^2/E')\,(B^2+3\,C^2/4) \quad . \quad . \quad . \quad . \quad (49)$$

For the minimum critical stress

$$\partial V/\partial A=\partial V/\partial B=\partial V/\partial C=0 \quad . \quad . \quad . \quad . \quad (50)$$

and eliminating the constants from the resulting linear homogeneous equations:—

$$\begin{vmatrix} 2k^2+(1-\sigma)g^2 & 0 & 0 \\ 0 & \begin{matrix}2g^2+(1-\sigma)k^2\\ +4k^2(1-\sigma)f\\ -2pk^2/E'\end{matrix} & 0 \\ 0 & 0 & \begin{matrix}3/2+f\{3/2\,k^4+8\,g^4\\ +3/2-3\,\sigma k^2+4(1-\sigma)k^2g^2\}\\ -(3/2)\,(pk^2/E')\end{matrix} \end{vmatrix}=0$$

$$. \quad . \quad . \quad . \quad . \quad . \quad (51)$$

From this determinant the minimum value for the critical stress will be given by the equation

$$p/E'=f\{k^2+(16/3)\,(g^4/k^2)+1/k^2-2\,\sigma+(8/3)\,(1-\sigma)\,g^2\}+1/k^2 \quad (52)$$

Providing k is large

$$p/E'=f\{k^2+(16/3)\,(g^4/k^2)+(8/3)\,(1-\sigma)\,g^2\}+1/k^2 \quad . \quad (53)$$

Remembering that

$$k=n\pi r/a,\ g=\pi m/\phi \text{ and } d=b^2/8\,r \quad . \quad . \quad . \quad (54)$$

$$p/E' = (\pi^2 t^2/12\,b^2)\,\{\, n^2b^2/a^2 + (16/3)\,(m^4a^2/n^2b^2) + (8/3)\,(1-\sigma)\,m^2 + (768/\pi^4)\,(d^2/t^2)\,(a^2/n^2b^2)\,\} \quad . \quad . \quad . \quad . \quad (55)$$

Put

$$K = n^2b^2/a^2 + (16/3)\,(m^4a^2/n^2b^2) + (8/3)\,(1-\sigma)\,m^2 + (768/\pi^4)\,(d^2/t^2)\,(a^2/n^2b^2) \quad (56)$$

It will be observed that this expression agrees with the corresponding expression for the similar case of the flat plate except for the additional curvature term

$$(768/\pi^4)\,(d^2/t^2)\,(a^2/n^2b^2) \quad . \quad . \quad . \quad . \quad (57)$$

Clearly, for a minimum value of K

$$m = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (58)$$

writing

$$a/nb = Q \text{ and } \sigma = 0.25 \quad . \quad . \quad . \quad . \quad (59)$$

$$K = 1/Q^2 + (16/3)\,Q^2 + 2 + (768/\pi^4)\,(d^2/t^2)\,Q^2 \quad . \quad . \quad (60)$$

For a maximum or minimum value of K

$$dK/dQ = 0 \quad . \quad . \quad . \quad . \quad . \quad (61)$$

Therefore

$$Q^2 = \{\, 16/3 + (768/\pi^4)\,(d^2/t^2)\,\}^{\frac{1}{2}} / \{\, 16/3 + (768/\pi^4)\,(d^2/t^2)\,\} \quad . \quad (62)$$

$$K_{\min} = 2\,\{\, [16/3 + (768/\pi^4)\,(d^2/t^2)]^{\frac{1}{2}} + 1\,\} \quad . \quad . \quad . \quad (63)$$

$$p/E'_{\min} = (\pi^2 t^2/12\,b^2)\,2\,\{\, [16/3 + (768/\pi^4)\,(d^2/t^2)]^{\frac{1}{2}} + 2\,\} \quad . \quad (64)$$

if $d/t = 0$,

$$K_{\min} = (8\sqrt{3})/3 + 2 \quad . \quad . \quad . \quad . \quad . \quad (65)$$

The value obtained for the corresponding case of the flat plate (9).

Fig. 4 shows the value for the factor K plotted against the bulge-thickness ratio for the two cases just considered.

In each case when $d/t = 0$ the value for K is the flat plate value, while in the case of the curved plate with simply supported edges the value of K when $d/t = 1.471$ agrees with the value obtained for a complete circular cylinder.

Equation (33) may be written as

$$p/E' = (\pi^2 t^2/12\,b^2)\,\{\, (96/\pi^2)\,[(1-\sigma^2)/3]^{\frac{1}{2}}\,(d/t)\,\} \quad . \quad . \quad (66)$$

The term in brackets is a linear expression in d/t and is a tangent to the curve

$$K = 4 + (192/\pi^4)\,(1-\sigma^2)\,(d^2/t^2) \quad . \quad . \quad . \quad (67)$$

and touches it when $d/t = 1.471$.

CASE (C). CIRCUMFERENTIAL EDGES SIMPLY SUPPORTED, ONE AXIAL EDGE FREE AND ONE AXIAL EDGE SIMPLY SUPPORTED. $\phi \gtrless \pi/2$.

The boundary conditions for this case will be

$$w = 0;\ \partial^2 w/\partial x^2 + (\sigma/r^2)\,(w + \partial^2 w/\partial\theta^2) = 0, \text{ when } x = 0 \text{ and } x = a \quad (68)$$

$$w = 0;\ (1/r^2)\,(w + \partial^2 w/\partial\theta^2) + \sigma\partial^2 w/\partial x^2 = 0, \text{ when } \theta = 0 \quad . \quad (69)$$

$$(1/r^2)\,(w + \partial^2 w/\partial\theta^2) + \sigma\partial^2 w/\partial x^2 = 0;$$

$$(1/r^3)\,(\partial w/\partial\theta + \partial^3 w/\partial\theta^3) + \{\, (2-\sigma)/r\,\}\,(\partial^3 w/\partial\theta\partial x^2) - 2\,(1-\sigma)\,(\partial^2\eta/\partial x^2) = 0, \text{ when } \theta = \phi \quad . \quad (70)$$

The displacement equations

$$u = A \sin\theta \cos(kx/r)$$
$$r\eta = B \cos\theta \sin(kx/r)$$
$$w = C \sin\theta \sin(kx/r) \quad . \quad . \quad . \quad . \quad (71)$$

will satisfy the boundary conditions at the supported edges, but, although satisfying the condition for no bending moment at the free edge, the condition for no shear and twisting along this boundary is not satisfied, *i.e.*,

$$(1/r^3)\,(\partial w/\partial\theta + \partial^3 w/\partial\theta^3) + \{\, (2-\sigma)/r\,\}\,(\partial^3 w/\partial\theta\partial x^2) - 2\,(1-\sigma)\,(\partial^2\eta/\partial x^2) \neq 0 \quad (72)$$

However, as the conditions at all the supported edges have been fulfilled it is very doubtful if the disregarding of the last condition at the free edge will have any appreciable effect on the value of the critical buckling stress.

Using the method described in the preceding cases we have

$$W = (hpk^2a/2r)\,(B^2S + C^2D) \quad . \quad . \quad . \quad . \quad (73)$$

where

$$S=\phi/2+\tfrac{1}{4}\sin 2\phi$$

and

$$D=\phi/2-\tfrac{1}{4}\sin 2\phi \quad . \quad . \quad . \quad . \quad (74)$$

$$(2r/E'ha)\ V=k^2A^2S+(C-B)^2\,D+\tfrac{1}{2}(1-\sigma)\,(Bk+A)^2\,S$$
$$+f\{C^2k^4D+2(1-\sigma)(C-B)^2k^2S\}$$
$$-pk^2/E'[B^2S+C^2D] \quad . \quad . \quad . \quad . \quad (75)$$

For V to have a minimum or maximum value for variations in A, B and C

$$\partial V/\partial A=0,\ \partial V/\partial B=0,\ \partial V/\partial C=0 \quad . \quad . \quad . \quad (76)$$

From which

$$\begin{vmatrix} 2k^2+(1-\sigma) & -2k^3S & 0 \\ (1-\sigma)k & -(2pk^2/E')S & k^4Df-(pk^2/E')D \\ 0 & -2D-4(1-\sigma)k^2Sf & D+\{k^4D+2(1-\sigma)k^2S\}f \\ & & -(pk^2/E')D \end{vmatrix}=0$$

$$. \quad . \quad . \quad . \quad . \quad (77)$$

From which, providing k is large,

$$p/E'=f\{k^2+2(1-\sigma)S/D\}+1/k^2 \quad . \quad . \quad . \quad (78)$$

this may be expressed in the form

$$p/E'=(\pi^2t^2/12\,b^2)\{n^2b^2/a^2+2(1-\sigma)(b^2/\pi^2r^2)[(\phi+\sin\phi\cos\phi)/(\phi-\sin\phi\cos\phi)]$$
$$+(768/\pi^4)(d^2/t^2)(a^2/n^2b^2)\} \quad . \quad . \quad . \quad . \quad (79)$$

Expanding $\sin\phi\cos\phi$ into a series and remembering that $\phi=b/r$ we have

$$(b^2/r^2)[(\phi+\sin\phi\cos\phi)/(\phi-\sin\phi\cos\phi)]$$
$$=(15-5\,b^2/r^2+b^4/r^4-\ldots)/(5-b^2/r^2+\ldots) \quad . \quad . \quad (80)$$

For the case when b/r is small, which obtains for most practical cases,

$$(b^2/r^2)[(\phi+\sin\phi\cos\phi)/(\phi-\sin\phi\cos\phi)]=3 \text{ approx.} \quad . \quad (81)$$

therefore

$$p/E'=(\pi^2t^2/12\,b^2)\{n^2b^2/a^2+(6/\pi^2)(1-\sigma)+(768/\pi^4)(d^2/t^2)(a^2/n^2b^2)\} \quad (82)$$

For the minimum critical stress the bracketed term, denoted by K must be a minimum.

This condition is given by

$$dK/dQ=0 \quad . \quad . \quad . \quad . \quad . \quad (83)$$

where

$$Q=a/nb \quad . \quad . \quad . \quad . \quad . \quad (84)$$

from which

$$K_{\min}=(2/\pi^2)\{16\sqrt{3}\,(d/t)+3(1-\sigma)\} \quad . \quad . \quad . \quad (85)$$

when $d/t=0$ the case of the flat plate

$$K_{\min}\to 6/\pi^2\,(1-\sigma)$$
$$\to 0.456, \text{ for } \sigma=0.25 \quad . \quad . \quad . \quad . \quad (86)$$

which agrees with the value obtained by Timoshenko when considering the stability of the flat plate (10).

It will be observed that for cases when $d/t=0$, K is a minimum when nb/a is a minimum, the smallest value of this ratio will be obtained when the plate buckles into a single half wave.

The value $K_{\min}=0.456$ can never be obtained for the case of the flat plate as b/a will never be equal to zero; actually

$$K_{\min}=0.456+b/a \quad . \quad . \quad . \quad . \quad . \quad (87)$$

and as

$$b/a\to 0,\ K_{\min}\to 0.456.$$

For the case when b/a is not small a large increase in the value of K will be obtained and for

$$d/t=0,\ b/a=1.0,\ K=1.456 \quad . \quad . \quad . \quad . \quad (88)$$

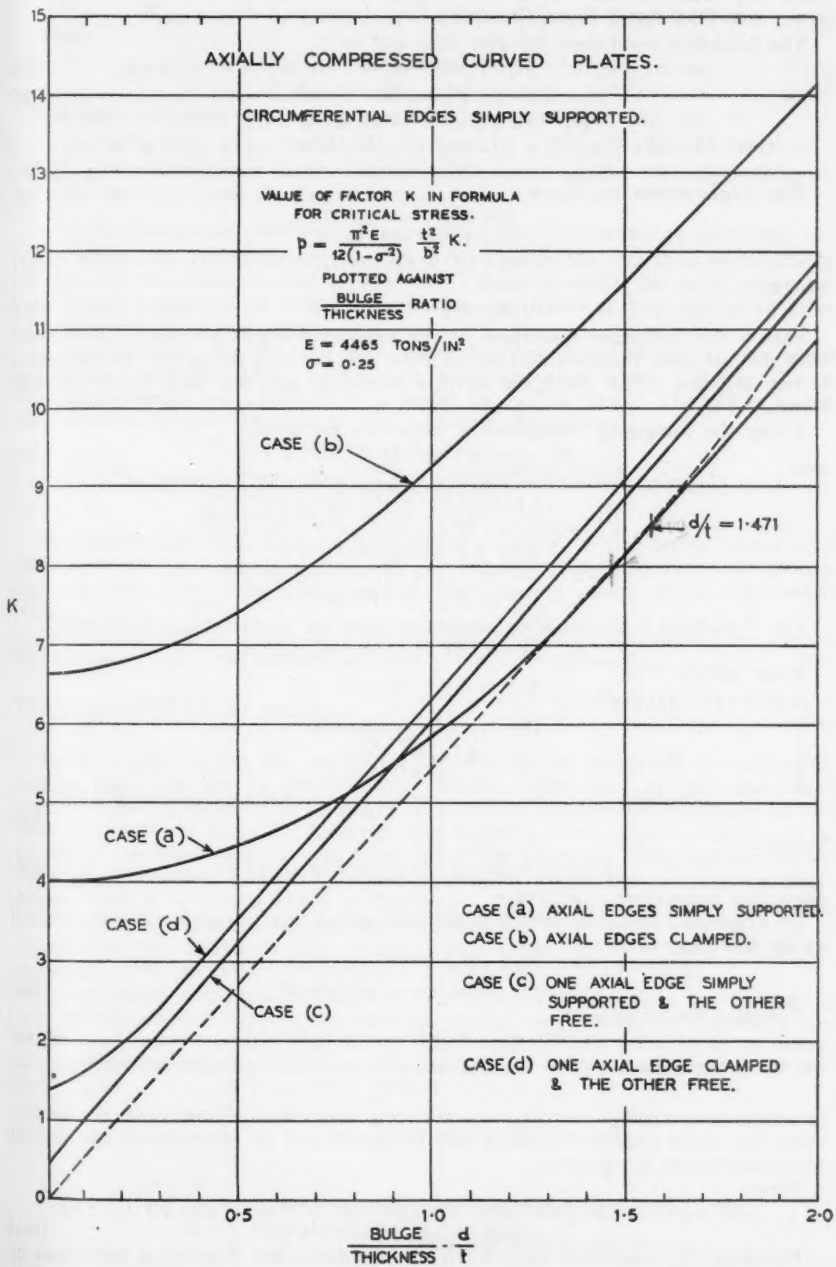

AXIALLY COMPRESSED CURVED PLATES.
CIRCUMFERENTIAL EDGES SIMPLY SUPPORTED.
VALUE OF FACTOR K IN FORMULA FOR CRITICAL STRESS.
$p = \frac{\pi^2 E}{12(1-\sigma^2)} \frac{t^2}{b^2} K.$
PLOTTED AGAINST
BULGE / THICKNESS RATIO
E = 4465 TONS/IN.²
σ = 0·25
CASE (b)
d/t = 1·471
CASE (a)
CASE (d)
CASE (c)
CASE (a) AXIAL EDGES SIMPLY SUPPORTED.
CASE (b) AXIAL EDGES CLAMPED.
CASE (c) ONE AXIAL EDGE SIMPLY SUPPORTED & THE OTHER FREE.
CASE (d) ONE AXIAL EDGE CLAMPED & THE OTHER FREE.
K
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0·5
1·0
1·5
2·0
BULGE / THICKNESS · d/t

FIG 4.

CASE (D). CIRCUMFERENTIAL EDGES SIMPLY SUPPORTED, ONE AXIAL EDGE FREE AND ONE AXIAL EDGE CLAMPED.

The boundary conditions for this case will be

$$w=0;\ \partial^2 w/\partial x^2+(\sigma/r^2)(w+\partial^2 w/\partial\theta^2)=0, \text{ when } x=0,\ x=a \quad . \quad (89)$$

$$w=0;\ \eta=0;\ \eta+\partial w/\partial\theta=0 \text{ when } \theta=0 \quad . \quad . \quad . \quad (90)$$

$$(1/r^2)(w+\partial^2 w/\partial\theta^2)+\sigma\partial^2 w/\partial x^2=0;$$
$$(1/r^3)(\partial w/\partial\theta+\partial^3 w/\partial\theta^3)+\{(2-\sigma)/r\}(\partial^3 w/\partial\theta\partial x^2)-2(1-\sigma)\partial^2\eta/\partial x^2=0,$$
$$\text{when } \theta=\phi \quad . \quad . \quad . \quad . \quad . \quad (91)$$

The displacement equations

$$u=Af(\theta)\cos(kx/r)$$
$$r\eta=Bf(\theta)\cos(kx/r)$$
$$w=Cf(\theta)\sin(kx/r) \quad . \quad . \quad . \quad . \quad (92)$$

where

$$f(\theta)=6\phi^2\theta^2-4\phi\theta^3+\theta^4 \quad . \quad . \quad . \quad . \quad (93)$$

Satisfy the boundary conditions at the supported edges although, in common with the last case, the condition for no shear and twisting along the free boundary is not satisfied. The disregard of this condition will not lead to any serious errors.

Using the foregoing displacement equations we obtain

$$W=(52\,hpk^2a\phi^9/45\,r)(B^2+C^2) \quad . \quad . \quad . \quad (94)$$

and

$$(45\,r/52\,E'ha\phi^5)\,V=k^2A^2\phi^4+(405/91)\,\phi^2B^2+\phi^4C^2-2\,\sigma k\phi^4AC$$
$$+\tfrac{1}{2}(1-\sigma)\{k^2B^2\phi^4+(405/91)\,\phi^2A^2\}$$
$$+f[\phi^4k^4C^2+\{\phi^4+(135/91)\,\phi^2+162/13\}C^2$$
$$-2\,\sigma k^2\{\phi^4+(135/182)\,\phi^2\}C^2$$
$$+2(1-\sigma)k^2\{(405/91)\,\phi^2C^2+\phi^4B^2\}]$$
$$-(p/E')\,k^2\phi^4(B^2+C^2) \quad . \quad . \quad . \quad . \quad (95)$$

For V to have a minimum or maximum value for variations in A, B and C

$$\partial V/\partial A=0,\ \partial V/\partial B=0,\ \partial V/\partial C=0 \quad . \quad . \quad . \quad (96)$$

From which

$$\begin{vmatrix} 2k^2\phi^4+(1-\sigma)(405/91)\,\phi^2 & 0 & -2\,\sigma k\phi^4 \\ & (810/91)\,\phi^2+(1-\sigma)k^2\phi^4 & \\ & +4(1-\sigma)k^2\phi^4 f & \\ 0 & -(2\,p/E')\,k^2\phi^4 & 0 \\ -2\,\sigma k\phi^4 & 0 & 2\phi^4+2fL-(2\,p/E')\,k^2\phi^4 \end{vmatrix}=0$$
$$\quad . \quad . \quad . \quad . \quad . \quad (97)$$

Where

$$L=\phi^4k^4+162/13+(135/91)\,k^2\phi^2(6-7\,\sigma) \quad . \quad . \quad . \quad (98)$$

negligible terms being omitted.

By expanding this determinant a solution with a useful significance is obtained in the following form:—

$$p/E'=f\{k^2+162/13\,k^2\phi^4+(135/91\,\phi^2)(6-7\,\sigma)\}+1/k^2$$
$$-\sigma^2/\{k^2+(1-\sigma)\,405/182\,\phi^2\} \quad . \quad . \quad . \quad . \quad (99)$$

Consider the expression

$$1/k^2-\sigma^2/\{k^2+(1-\sigma)\,405/182\,\phi^2\} \quad . \quad . \quad . \quad (100)$$

the maximum possible value for the last term of this expression would be

$$\sigma^2/k^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (101)$$

in which case, taking $\sigma=0.25$, it would only amount to $6\frac{1}{4}$ per cent. of the first term, for most practical cases ϕ will be small and in consequence the second term may safely be ignored.

Then

$$p/E'=(\pi^2t^2/12\,b^2)[n^2b^2/a^2+(162/13\,\pi^4)(a^2/n^2b^2)+(135/91\,\pi^2)(6-7\,\sigma)$$
$$+(768/\pi^4)(d^2/t^2)(a^2/n^2b^2)] \quad . \quad . \quad . \quad . \quad (102)$$

Denoting the bracketed term by K the condition for it to be a maximum or minimum will be given by

$$dK/dQ=0, \text{ where } Q=a/nb \quad . \quad . \quad . \quad . \quad (103)$$

Whence

$$K_{min} = (1/\pi^2) \{ 2 (162/13 + 768 d^2/t^2)^{\frac{1}{2}} + (135/91) (6 - 7\sigma) \} \quad . \quad (104)$$

When

$$d/t = 0 \text{ and } \sigma = 0.25 \quad . \quad . \quad . \quad . \quad . \quad (105)$$

$$K_{min} = 1.354, \; a/nb = 1.635 \quad . \quad . \quad . \quad . \quad (106)$$

The value obtained for the corresponding flat plate case (10) was

$$K_{min} = 1.328$$

Fig. 4 shows the value for the coefficient K plotted against the bulge-thickness ratio for the four cases considered in this work.

VI. A Comparison Between Theoretical and Experimental Results.

The writer has not made any tests on curved plates but test data are available for the first two cases studied in this paper, those in which the axial edges are both simply supported or both clamped. No experimental data appear to exist regarding the other two cases.

A large number of tests have been made by Newell and Gale (11) on curved unstiffened duralumin plates with simply supported axial edges. The results of these experiments are tabulated in a report by Sechler (12). The plates tested were made from combinations of the following dimensions:—

6, 9, 12 inches long.
3, 6, 9, 12 inches circumferential width.
5, 10, 20, 30 inches radius.
0.0200-0.0520 inches thick.

The results show that there is a consistent variation in the critical stress with the length and to a lesser degree, with the breadth of the specimen, the shorter and narrower specimens giving values more nearly equal to the theoretical results.

The results for the plates 6 inches in length* are shown plotted on Fig. 5 and compared with the theoretical value given by equation (34)

$$p = [1/3 (1 - \sigma^2)]^{\frac{1}{2}} E (t/r)$$

which applied to all the results as

$$d/t > 1.471$$

Sechler suggests that the reason for the decrease in the stress for increasing lengths might be due to the following causes. The sides of the sheet were supported in V grooves with an angle of 45° which initially held the edge of the sheet in a straight line. If, however, any buckling takes place in the centre of the sheet, the edges were free to move out of the grooves. This motion allowed the edge of the sheet to deflect perpendicular to its length and to act as an Euler column with a restricted range of buckling. This would tend to decrease the load carried by the edge regions and this buckling load would very likely be a function of the length of the column. This seems to be a very reasonable explanation.

In connection with the second case in which the axial edges are clamped a very careful series of experiments has been carried out by Cox and Clenshaw (13) at the National Physical Laboratory. These experiments were made on sheets of duralumin having the following dimensions:—

0.067 inch thick
0.038 ,,
0.030 ,,
0.020 ,,
0.017 ,,
} Curved to 18-inch radius.

4, 6, 8, 10 and 12 inches wide (circumferentially).

0.067 inch thick
0.038 ,,
} Curved to 36-inch radius.

* The plates 9 inches and 12 inches long give, on the average, 87 per cent. and 75 per cent. of these results.

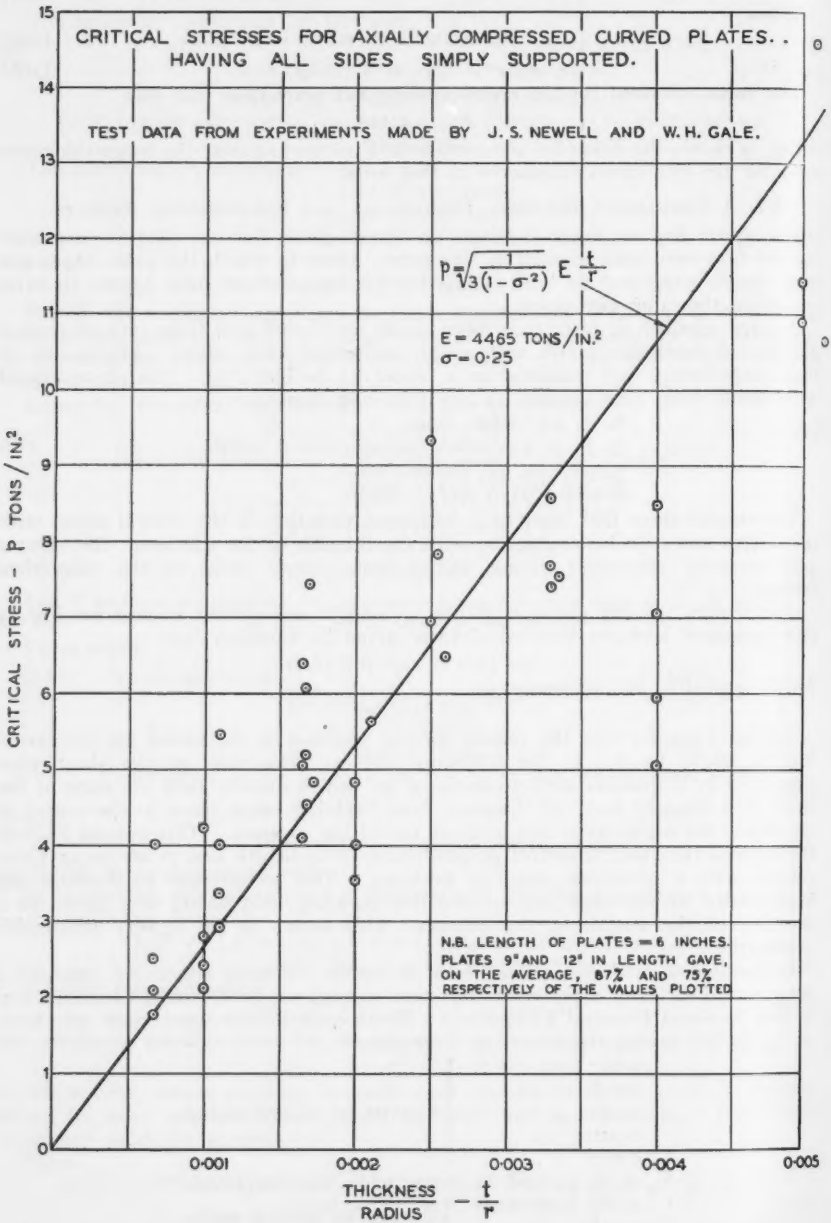

CRITICAL STRESSES FOR AXIALLY COMPRESSED CURVED PLATES. . HAVING ALL SIDES SIMPLY SUPPORTED.
TEST DATA FROM EXPERIMENTS MADE BY J. S. NEWELL AND W. H. GALE.
$p = \sqrt{\frac{1}{3(1-\sigma^2)}}\, E \frac{t}{r}$
E = 4465 TONS/IN.²
σ = 0·25
N.B. LENGTH OF PLATES = 6 INCHES. PLATES 9" AND 12" IN LENGTH GAVE, ON THE AVERAGE, 87% AND 75% RESPECTIVELY OF THE VALUES PLOTTED
CRITICAL STRESS - p TONS/IN.²
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0·001 0·002 0·003 0·004 0·005
THICKNESS / RADIUS = $\frac{t}{r}$

FIG. 5.

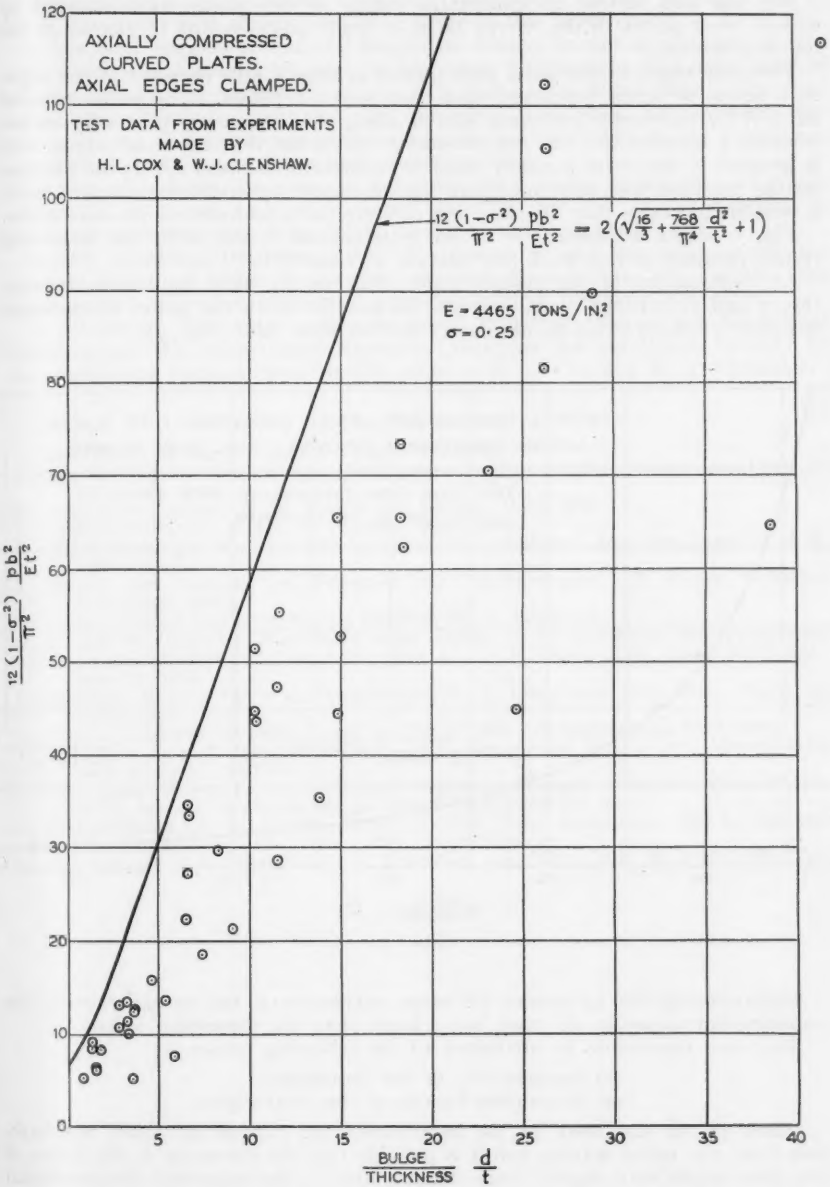

AXIALLY COMPRESSED
CURVED PLATES.
AXIAL EDGES CLAMPED.
TEST DATA FROM EXPERIMENTS
MADE BY
H.L. COX & W.J. CLENSHAW.
$\frac{12(1-\sigma^2)}{\pi^2}\frac{pb^2}{Et^2} = 2\left(\sqrt{\frac{16}{3}+\frac{768}{\pi^4}\frac{d^2}{t^2}}+1\right)$
E = 4465 TONS/IN.²
σ = 0·25
$\frac{12(1-\sigma^2)}{\pi^2}\frac{pb^2}{Et^2}$
BULGE / THICKNESS $\frac{d}{t}$
0
10
20
30
40
50
60
70
80
90
100
110
120
5
10
15
20
25
30
35
40

FIG. 6.

The axial length of all the plates was 24 inches. The displacements in the direction of the load were measured over the whole panel.

The top and bottom circumferential edges of the plates were clamped by curved cover plates to the curved faces of angle pieces bolted to platens at the top and bottom.

The axial edges of the panel were guided in slots $\frac{3}{8}$ inch deep cut in the edges of a series of strips supported upon two pairs of pillars. The strips were of 16 S.W.G. duralumin and were spaced along the supporting pillars by rubber washers $\frac{1}{4}$ inch thick. The experimenters considered that the axial edges, held in grooves in the above manner, could be considered clamped. A 25-ton Denison testing machine was used incorporating adjustable spherical seats which made it possible to ensure that the plate was subjected to a uniform compressive strain.

Fig. 6 shows a comparison of the experimental results with the theoretical results obtained in this work (see Section V, Case (B)).

An examination of the results shows that an excellent agreement between theory and experiment is obtained for the case in which the radius of curvature is equal to infinity; this is, of course, the flat plate case (Fig. 7).

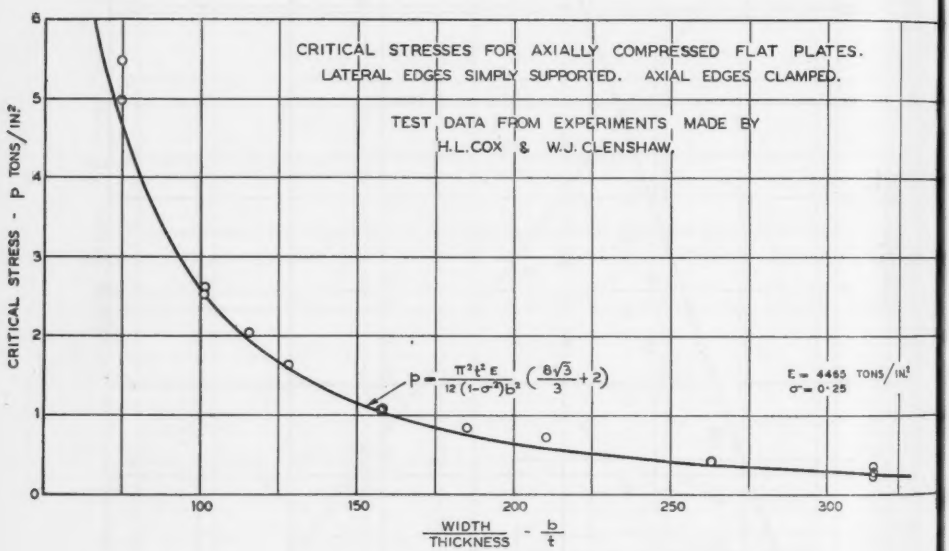


FIG. 7.

Unfortunately the agreement for other curvatures is not so satisfactory, the experimental values in all cases being lower than the theoretical values.

This may reasonably be attributed to the following causes:—

(1) Imperfection in the specimens.
(2) Incomplete fixation of the axial edges.

Plates of the size used for the experiments are difficult to obtain absolutely free from any initial waving and it is possible that the curvature at the centre of the plate might vary slightly from the curvature at the supported circumferential edges.

Regarding the second cause it will be realised that it is almost impossible to obtain complete edge fixation and it is reasonable to expect that the experimental results would be lower than the theoretical figures for this reason. Actually

in some cases the tests give values lower than the theoretical stresses which would be obtained if the edges were taken as simply supported.

Experimental results obtained for axially compressed circular tubes are not in closer agreement with theory than those given in this paper (14).

It has been suggested that the theoretical results do not agree more closely with experimental results because the assumed displacement equations used in the analysis do not necessarily agree with the actual displacements observed during test. Actually, provided the boundary conditions are satisfied any reasonable set of displacement equations should lead to solutions not more than 10 per cent. in excess of the actual critical stresses.

On the other hand, the practical difficulties both in the setting up and in the application of a load to a thin curved plate for test and in the difficulty in obtaining specimens free from initial distortion are very great.

Broadly speaking, the tester takes the theorist to task for not allowing for practical variations while the theorist, perhaps more unreasonably, wishes the tester would use perfect plates and reproduce perfect boundary conditions.

In conclusion, the writer wishes to thank Professor Pippard for his helpful criticisms and the Aeronautical Research Committee for permission to refer to the compression tests on curved panels made by H. L. Cox and W. J. Clenshaw.

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ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry.

(Prepared by R.T.P.)

No. 55. MAY, 1938.

Munitions Manufacture. (H. Hoerschelmann, Z.V.D.I., Vol. 82, 1/1/38, pp. 3-7. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 50.) (55/1 Germany.)

The author observes that munitions manufacture is not essentially different from other branches of engineering, but that, on account of the purposes in view, quality and reliability are of unusual importance. He states that during the war functional failure of certain stores led to breakdown of important plans, and he contrasts the usual commercial considerations of price and limited market with the military view of necessity and large production in a limited time. He indicates the necessity for reserve stores and for protection against their deterioration. He cites two examples from practice in which the various tolerances are batched in groups, demonstrating that most parts do not require extreme accuracy. He considers that hand polishing methods can be largely replaced by buffing and grinding. He emphasises the importance of interchangeability of parts, and indicates how by special machines this can be readily obtained. Inspection of munitions must be quite different from that of other products, because not only are the functional importance and the interchangeability inescapable, but also the product is State property and the inspector must be governed by clear rules and specifications—never by discretion.

Portable Wireless Stations. (H. Neumann, W.T.M., Vol. 42, No. 1, Jan., 1938, pp. 23-33.) (55/2 Germany.)

The following types are described:—

Power (watt).	Wavelength (m.).	Range (km.).	Weight (kg.).
5	96—316	20— 80	90
1	60—100	12— 20	56
15	60—100	30—100	70
15	40—100	30—100	89

The shorter of the two ranges stated refers to telephonic communication.

The 1 watt station, fitted with accumulators instead of hand-operated dynamo, only weighs 37 kg. and is arranged in two separate packs which can be easily carried by two soldiers. Communication can then be maintained on the march. The operation of the hand dynamo is specially silenced so that the apparatus can be used in the front line trenches.

(Reference should also be made to Abstracts No. 51, item 62, where particulars of a light weight wireless set suitable for gliders are given. This set only weighs 4.5 kg. and has a range of 20 km.)

Aircraft Reconnaissance at Night. (F. Lohle, W.T.M., Vol. 42, No. 3, March, 1938, pp. 125-133, and No. 4, April, 1938, pp. 170-178.) (55/3 Germany.)

The author investigates the physical basis underlying the observation of ground details from great heights, assuming a clear sky and no moon (starlight and no clouds). It is well known that under these circumstances the ground illumination may vary over wide limits with no apparent reason, but exceptionally bright nights usually occur in August and December (at any rate in Germany).

The source of the illumination has not yet been satisfactorily determined, but it is certain that the starlight can only be responsible for a very small proportion of the total. It appears probable that the sunlight is indirectly responsible, the upper atmosphere being under electrical excitation (electron bombardment). One peculiarity of this light from the sky is the fact that the slight haze generally present in the lower layers of the atmosphere is also rendered luminous and, seen from above, the ground details (already rendered difficult to observe on account of the faint light) are obscured still further.

The author considers the minimum size of black objects on a white background which can be distinguished by the eye under various degrees of illumination and extends the case to the effect of differences in contrast and the presence of luminous haze.

Night glasses are only beneficial if of sufficient magnification (30 x) and this is difficult to provide for in aircraft (vibration, etc.). According to the author, the new German motor roads are completely invisible from an altitude of 6,000 m. in the absence of moonlight.

Air Attacks on Barcelona. (Les Ailes, No. 881, 5/5/38, p. 11.) (55/4 Spain.)

For the attack, bombs weighing 500, 100 and 50 kg. were employed. The aircraft operated in groups of three or six at altitudes between 4,000 and 6,000 m. The bombs were dropped at the rate of approximately 1 ton per hour, 350 hits being scored.

As the raiding aircraft approached from the sea at a speed of the order of 380 km./h., no previous warning could be given to the civilian population.

Balloon Barrages and Atmospheric Electricity. (D. Lautner, Luftwehr, Vol. 5, No. 2, Feb., 1938, pp. 66-70.) (55/5 Germany.)

The atmosphere may be considered as a partly conducting dielectric between the earth surface and the Heaviside layer. Whilst the conductivity of the earth surface and the Heaviside layer are approximately equal (6×10^5 sec^{-1}), the conductivity of the lower atmosphere is very much less (5×10^{-4} sec.$^{-1}$).

For some as yet unknown reason, the earth surface is constantly charged with approximately -5×10^{-5} coulombs. This charge necessitates a potential difference of the order of 200,000 volts between the Heaviside layer and the surface of the earth, the gradient being steepest near the surface, *i.e.*, up to 6 km. This means that a balloon barrage has to operate (even in the absence of electric storms) under conditions of considerable electrical stress (earthed cable).

Matters are, however, made very much worse if a thunderstorm intervenes. The author briefly reviews modern theories and calculates that even a moderate stroke of lightning will completely vaporise 4 km. of iron wire 1.6 mm. diameter. The only protection is to wind up the balloon if there is any chance of a storm and the barrage must therefore rely on an efficient meteorological service. Waiting till thunder is heard is fatal, since the storm may be overhead within a few minutes whilst it takes at least half an hour to descend the balloon.

New War Gases for Old? (C. E. Brigham, Army Ordnance, Vol. 18, No. 108, May-June, 1938, pp. 334-338.) (55/6 U.S.A.)

One ton of mustard gas possesses sufficient toxicity to kill 45,000,000 people—if it could be administered without waste.

Statistics of the world war have shown that one ton of this gas had to be used to produce 20 casualties, of which one was fatal.

It is thus evident that the military scientist has more to gain by improving the efficiency in the utilisation of known gases (which are amply toxic) than from a quest of new agents of greater inherent power.

A case in point is the German Blue Cross gas (diphenyl chlorarsine) which was a failure in the war because the proper technique of dispersion was not mastered in time.

This difficulty has now been overcome and very efficient gas masks are required to withstand the action of this poison.

Masks of this type are uncomfortable to wear and affect both the mobility, fighting power and morale of the troops.

These secondary effects of chemical warfare are almost as important as the production of fatal casualties.

(See also Translations Nos. 641A to 641E, which cover various aspects of chemical warfare with special reference to dissemination by aircraft.)

On the Motion of a Fluid Heated from Below. (R. J. Schmidt and O. A. Saunders, Proc. Roy. Soc., Series A, Vol. 165, No. 921, 5/4/38, pp. 216-28.) (55/7 Great Britain.)

If a horizontal layer of fluid, initially at rest, is heated from below, instability and cellular motion set in when λ ($\equiv \alpha g c (\theta_1 - \theta_2) d^3 K \nu$) is about 1,700. Experiments for several layer depths show that on further heating the layer becomes completely turbulent at about $\lambda = 45{,}000$. Observations by an optical method indicate that in the case of water the turbulence develops suddenly, but that in air the transition is more gradual, the first signs of turbulence occurring at about $\lambda = 5{,}000$. The rate of heat transfer is measured at each stage, and the increase at the change from cellular to turbulent motion is found to be less than that at the change from equilibrium to cellular motion.

$\lambda = dgc (\theta_1 - \theta_2) d^3 / k\gamma$.
α = expansion coefficient.
c = specific heat per unit volume.
γ = kinematic viscosity.
K = thermal conductivity.
d = distance between plates.
g = gravity acceleration.

Drag of Cylinders of Simple Shape. (W. F. Lindsey, N.A.C.A. Report No. 619, 1938.) (55/8 U.S.A.)

In order to determine the effect of shape, compressibility, and Reynolds number on the drag and critical speed for simple forms, the drag forces on models of various simple geometric cross sections were measured in the N.A.C.A. 11-inch wind tunnel.

The models were circular, semitubular, elliptical, square and triangular (isosceles) cylinders. They were tested over a speed range from 5 per cent. of the speed of sound to a value in excess of the critical speed, corresponding, for each model, approximately to a tenfold Reynolds number range, which extended from a minimum of 840 for the smallest model to a maximum of 310,000 for the largest model.

The following are the main conclusions:—

1. The compressibility effects appear to be independent of Reynolds number for ranges wherein there are no marked changes in the flow pattern caused by Reynolds number effects.
2. The critical speed of elliptical cylinders decreases with decrease in fineness ratio.
3. For bodies having sharp edges that may be expected to define the separation point, the Reynolds number effects are small. This result substantiates earlier investigations.

Effect of Change in Cross-Section on the Velocity and Pressure Distribution of Turbulent Flow in Pipes. (E. Mayer, Forschungsheft 389, March-April, 1938.) • (55/9 Germany.)

In practical engineering the case often arises of the cross-section of a channel altering its shape as we proceed along the channel.

The author investigates the case of variation from circular to rectangular cross-section of equal area and vice versa, using air as the flowing medium. The circular diameter was 190 mm. and the rectangle 119 × 238 mm. The total distance during which the change in shape takes place varied between 110 and 440 mm., the change being carried out smoothly in every case, the area remaining constant throughout.

The length of inlet pipe was chosen so that fully turbulent flow was established before the change in shape took place.

Numerous velocity and pressure profiles were obtained over the section undergoing the change in shape and the resistance co-efficient of this section was determined. In no case was there any evidence of separation of flow.

Dust Separation with the Cyclone Fan (Vortex Sink). (E. Feifel, Forschung., Vol. 9, No. 2, March-April, 1938, pp. 68-81.) (55/10 Germany.)

Along with all problems of dust technique the simple and cheap method of dust separation with the cyclone is gaining increasing economic importance. The action of the cyclones and their dimensions have as yet been considered chiefly empirically. In order to establish dependable data for designing a cyclone, it is necessary to determine the flow within the cyclone, and more especially within the dust-charged whirl, by calculation and to direct it by suitable construction. By considering the flow for the first time as an ideal vortex sink, the author has succeeded in calculating the influence of the most diverse service conditions. The flow theory then furnishes the means of producing within the whirl chamber of the cyclone a gas motion approaching the ideal flow of the vortex sink. Tests on the model and on working constructions prove the appropriateness of the method of calculation and of the corresponding design measures.

The Turbulent Flow of a Fluid in a Straight Pipe of Annular Cross-Section. (In English.) (V. Mikrjukov, Tech. Physics of the U.S.S.R., Vol. 4, No. 11-12, Nov.-Dec., 1937, pp. 961-77.) (55/11 U.S.S.R.)

1. Turbulent motion of liquid was studied in a straight tube of annular cross-section.

2. In this case the distribution of velocities in the cross-section is asymmetrical.

3. Study of the friction stress on the internal and external walls of the tubes showed that it is approximately three times greater on the inner wall than on the outer one.

4. It was found that Prandtl's and Kàrmàn's theory of turbulent flow is qualitatively applicable to the case of a straight tube of annular cross-section.

Taking the universal constant in Kàrmàn's equation $x=0.24$, good qualitative agreement is obtained between the experimental points and Kàrmàn's theoretical curve.

The Influence of Wall Oscillations, Wall Rotation and Entry Eddies on the Breakdown of Laminar Flow in an Annular Pipe. (A. Fage, Proc. Roy. Soc., Series A, Vol. 165, No. 923, 27/4/38, pp. 501-28.) (55/12 Great Britain.)

1. Scope of work. Experiments have been made to determine the effects of disturbances of known character on the laminar flow of water in a long pipe of annular cross-section. The disturbances considered are those due to axial oscillations of the inner wall of the pipe, to oscillations of the inner wall about its axis, and to both weak and intense entry eddies. Experiments on the breakdown due to a uniform rotation of the inner wall (outer wall fixed) have also been made.

The breakdown of flow near a plane surface oscillating in a stationary fluid has been observed.

2. The frequency of the axial oscillation of the inner wall when a departure from laminar flow occurs depends on the axial amplitude of the wall and the viscosity of the fluid, and is independent, within the accuracy of measurement, of the velocity of axial flow.

The results with the inner wall of the pipe oscillating longitudinally suggest that the flow remains laminar up to the critical Reynolds number of disturbance measured with the inner wall oscillating axially.

When the inner wall rotates at a uniform speed (outer wall stationary), the critical rotational speed increases with the axial speed of flow; and the critical number for no axial flow, predicted by extrapolation of the curve drawn through the numbers measured with axial flow, is in close agreement with Taylor's theoretical number.

It is shown that the early breakdown of laminar flow associated with intense entry disturbances can be caused by very weak entry disturbances, provided they are in the form of discreet eddies.

Transport of Electric Ions Applied to Supersonic Speed Measurements. (V. Volkovisky, Comp. Rend., Vol. 206, No. 14, pp. 1084-1086.) (55/13 France.)

The authors carried out experiments with insulated electrodes embedded in the wall of a tube, the air current moving at speeds varying from the velocity of sound to three times the magnitude. The following results were obtained:—

1. The ionisation current is a function of the power input and the Mach number.

$$i=f(W, V/a)$$

provided $W>W_0$.

2. With $W=$constant, i is an increasing function of V/a, tending asymptotically to the saturation value which depends on W.
3. If the ionisation is confined to the boundary layer, i is increased.

The author suggests applying the method to velocity measurements in the boundary layer of a body under supersonic flow conditions.

Interference of Wing and Fuselage from Tests of 17 Combinations in the N.A.C.A. Variable Density Tunnel Combinations with Special Junctures. (A. Sherman, N.A.C.A. Tech. Note No. 641, March, 1938.) (55/14 U.S.A.)

As part of the wing fuselage interference programme in progress in the N.A.C.A. variable density tunnel, a method of eliminating the interference burble associated with critical midwing combinations was investigated. The interference

burble of the critical midwing combination was shown to respond to modifications at the nose of the juncture and to be entirely suppressed with little or no adverse effect on the high speed drag by special leading edge fillets.

Interference of Wing and Fuselage from Tests of Eight Combinations in the N.A.C.A. Variable Density Tunnel Combinations with Tapered Fillets and Straight Side Junctures. (A. Sherman, N.A.C.A. Tech. Note No. 642, March, 1938.) (55/15 U.S.A.)

The round fuselage of an unfilleted low wing combination was modified to incorporate straight-side junctures. The resulting combination, with or without horizontal tail surfaces, had practically the same aerodynamic characteristics as the corresponding round-fuselage tapered-fillet combination.

Comparative Flight and Full-Scale Wind Tunnel Measurements of the Maximum Lift of an Aeroplane. (A. Silverstein, S. Katzoff and J. A. Hootman, N.A.C.A. Report No. 619, 1938.) (55/16 U.S.A.)

Determinations of the power-off maximum lift of a Fairchild 22 aeroplane were made in the N.A.C.A. full-scale wind tunnel and in flight. The results from the two types of test were in satisfactory agreement. It was found that, when the aeroplane was rotated positively in pitch through the angle of stall at rates of the order of 0.1° per second, the maximum lift coefficient was considerably higher than that obtained in the standard tests, in which the forces are measured with the angles of attack fixed. Scale effect on the maximum lift coefficient was also investigated.

A Study of Flying Boat Take-off. (W. S. Diekl, N.A.C.A. Technical Note No. 643, April, 1938.) (55/17 U.S.A.)

The conclusions indicated by this study are as follows:—

1. The resistance curve for a flying boat may, in general, be satisfactorily approximated by two straight lines.

2. A graphical solution of the equations based on the linear approximation gives satisfactory agreement with step-by-step integration.

3. The relative distance and time required to reach hump speed depend largely on the value of the accelerating force at high speeds; the effect of variation in static thrust is small and the effect of variation in accelerating force at the hump is negligible.

4. Neglecting any effects due to variation in thrust with speed, the effect of a reasonable variation in the actual hump speed is negligible, except for very heavily loaded seaplanes.

5. Where take-off distance is a consideration, it may be advisable to accept a high hump resistance in order to obtain low planing resistance. The take-off time will depend only on the average accelerating force.

6. The take-off charts may be employed to determine the accelerating forces required to meet specified take-off performance.

The Oetiker Engine Brake. (F. Weiner, Autom. Tech. Zeit., Vol. 41, 25/1/38, pp. 31-3. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 40.) (55/18 Germany.)

The author describes the construction and action of the Oetiker brake system, which depends upon the pressure in the exhaust pipe acting on a cylinder piston system with the usual linkage. The brake system includes a hand lever operating a slide valve on the exhaust pipe and a control on the inlet pipe, which in carburettor engines opens an air valve and in diesel engines cuts out the fuel pump. The slide valve on the exhaust pipe is duplex in that a small valve is used to relieve the pressure on the main valve; both valves are sealed by the

exhaust gas pressure, and movement of a single valve would need too much effort. The pressures utilised are of the order of 2-4 atm., and the system is self-regulating since an accumulated pressure in the exhaust pipe will lift the exhaust valves against their springs and thus cut out the engine as a compressor. When the brake system is operated by the hand lever, a storage cylinder is charged with filtered exhaust gas. When the vehicle is to be braked the usual foot-pedal is depressed, and this opens a valve from the storage cylinder to a Westinghouse low pressure brake cylinder of the usual type.

Experiments on the Hesselman Engine. (W. Wilke, Autom. Tech. Zeit., Vol. 41, 25/1/38, pp. 25-30. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 40.) (55/19 Germany.)

The author divides internal combustion motors into five categories, ranging from the low compression Otto motor with spark ignition and low compression to the high compression, compression ignition, Diesel motor using heavy fuel. The Hesselman motor is in the central category, with medium compression medium fuel, and spark ignition with pump injection. A table contrasts the main characteristics of the Otto and Diesel motors in regard to knocking. Seven factors cause increase of knocking in the one and decrease of knocking in the other; for example, in the Diesel motor lead tetra ethyl and iron carbonyl cause knocking, which they inhibit in the Otto motor. The Hesselman motor represents a blend of extremes midway between the defects of both types. The author reproduces diagrams of the latest Hesselman arrangements with spark advance linked to a fuel pump for partial load operation, and curves illustrating engine performance under various conditions of injection timing, injection duration, ignition timing, and with light and heavy fuels of various cetane contents and with alcohol additions. The author asserts that the Hesselman motor can utilise light fuels unsuitable for carburettor engines, and heavy fuels unsuitable for Diesel engines, whilst on account of the spark ignition it offers considerable promise as a high speed, two-stroke engine of light weight for traction purposes.

Starting Troubles in Vehicle Diesel Motors. (R. Johannis, Autom. Tech. Zeit., Vol. 41, 25/1/38, pp. 34-9. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 45.) (55/20 Germany.)

On the basis of experience gained in a German armoured-car school, the author presents a comprehensive treatment of the starting problem, which, he states, arises every winter. Curves illustrate the temperature producible by various compression ratios when the engine is warm and when cold, and others indicate the starter h.p. required and available at various air temperatures. The causes of failure to start are classified as follows:—(1) battery exhaustion; battery too small, and other electrical defects; poor compression due to cylinder and piston wear; and unduly thick lubricating oil; (2) derangements in the Diesel engine; the author discusses fuel supply, heating coil action; injection timing; injection nozzles; injection pump; and the filter-cum-pipe system.

Within limits the author recommends the use of an enriched mixture for starting; but he utters a serious warning against excess. He also indicates emergency measures, which should be forbidden in normal circumstances, *e.g.*, towing a vehicle and throwing in the clutch or admitting petrol vapour or acetylene gas to the inlet pipe. Under careful control calcium carbide and water afford a handy adjunct for assisting a Diesel engine to start.

Fabric Gears. (E. W. Brown, Metropolitan Vickers Electrical Co., Ltd., Tech. News Bulletin, No. 608, 29/4/38, p. 2. Power Transport, April, 1938, pp. 152-8.) (55/21 Great Britain.)

This is a symposium relative to the general design and construction of fabric gears, with particular reference to the process involved in fabrication. The

article deals with the subject by discussing its leading features under the following headings:—Characteristics of the ideal gear and its construction; fabric materials now used; their physical mechanical properties; construction and the methods of fitting shrouds and bushes; types of fabric gear; gear design, gear teeth; lubrication; operation; machining, sawing, trepanning, drilling, turning, tapping and gear and screw cutting in fabric gear material.

Illustrated with six diagrams.

The Friction of Reciprocating Engines. (F. H. Dutcher, Trans. A.S.M.E., Vol. 60, No. 3, April, 1938, pp. 225-32.) (55/22 U.S.A.)

The paper contains a description of an automotive engine and cradle dynamometer set-up used in tests for ascertaining the following relations (*a*) Pumping losses versus r.p.m. for different manifold pressures, (*b*) total friction mean pressure (pumping plus mechanical) versus r.p.m. at different manifold pressures, (*c*) total friction mean pressure versus mean pressure on the pistons at different constant speeds, (*d*) mechanical friction mean pressure versus r.p.m. at different manifold pressures, (*e*) mechanical friction mean pressure versus mean pressure on the pistons at different constant speeds. These relations are all presented graphically. It appears that the friction m.e.p. increases appreciably under load and the losses are thus greater than commonly appreciated (similar conclusions were arrived at by British Air Ministry tests in 1925).

Thrust Bearings. (F. C. Linn and R. Sheppard, Trans. A.S.M.E., Vol. 60, No. 3, April, 1938, pp. 245-52.) (55/23 U.S.A.)

From a standpoint of thrust bearing design, there are two fundamentally different types of prime movers in use, namely: (1) The vertical shaft waterwheel generators which are massive, operate from low to moderate speeds, and have the weight of the rotating parts plus or minus the hydraulic thrust carried by the thrust bearing; (2) the horizontal shaft steam turbines which operate from moderate to high speeds and where the thrust load increases from a small value at zero torque to high values at maximum torque. For the first type of machinery, the flexibly supported thrust bearing is used and for the latter, the tapered land thrust bearing. There are also a large number of steam turbines in regular service to-day operating with "marine-type thrust bearings." The authors deal more fully with the flexibly supported and tapered land thrust bearings and describe suitable test plants for these bearings.

In an appendix the classical theory of lubrication as applied to rectangular surfaces is extended to include helicoidal surfaces.

Engines and Propellers for Powered Gliders and Light Aeroplanes. (Gropp, H., Flugsport, Vol. 29, No. 24, 24/11/37, pp. 663-671. Available as Translation T.M. 850.) (55/24 Germany.)

Light aeroplane engines are conveniently designed as high-speed engines (the term "high-speed" being understood to mean speeds of 3,000 to 4,000 revolutions per minute). In those cases where a definite useful power, to be expressed conventionally by the maximum climb velocity of the aeroplane, is to be attained with the smallest engine weight, the propellor should be the direct drive type. If economical operation—that is, the best possible flight performance for a given power developed by the engine, or for a given fuel consumption is the factor of importance—then a gear-driven propeller is recommended, the reduction ratio of which is determined by the maximum allowable propeller diameter. The propeller speed will then be about 600 to 1,000 revolutions per minute.

Auto-Ignition and Combustion of Diesel Fuel in a Constant Volume Bomb. (R. F. Selden, N.A.C.A. Report No. 617, 1938.) (55/25 U.S.A.)

The following are the main conclusions:—

1. For fuel injection into a constant volume bomb containing stagnant air at a temperature and a pressure approximating those in a compression-ignition engine, the ignition lag was essentially independent of the injected fuel quantity and was of the same magnitude as in the engine.

2. For the fuel used, the possible decrease in the ignition lag for a given increase in air temperature or density became quite small at temperatures and densities in excess of those generally occurring in compression-ignition engines.

3. The combustion efficiency improved as the ignition lag was lengthened; hence it should be worth while to use those fuels in an engine whose ignition lags correspond to the higher permissible rates of pressure rise. The useless "after-burning" decreased as the ignition lag was lengthened.

4. The ignition lag tended to increase and the maximum rate of pressure rise definitely decreased upon the addition of inert gases to an air charge of fixed concentration.

Oil Sprays: An Investigation of Velocities and Penetrations. (P. H. Schweitzer, Autom. Eng., Vol. 28, February, 1938, pp. 61-4. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 41.) (55/26 Great Britain.)

The author describes experiments made by timing the interval between the opening of the spray-valve and the impingement of the spray on a sensitive electrical contact at various distances. He concludes that the spray in ordinary Diesel engines is not influenced by the injection duration, the penetration of an intermittent spray being generally similar to that of a stationary spray. Concise rules are given for calculating spray penetration and velocity.

Investigation of the Atomisation of Liquid Fuel. (In English.) (L. Strazhevski, Tech. Physics, U.S.S.R., Vol. 4, No. 11-12, Nov.-Dec., 1937, pp. 978-1003.) (55/27 U.S.S.R.)

The purpose of this investigation was to study the quality of atomisation of liquid fuel when injected at relatively low pressures from 25 to 150 kg./cm.^{2} (excess). Three series of experiments were carried out: The injection of benzine in calm air, injection of benzine in a counter-stream of air and injection of kerosene in calm air.

The injections were made in a medium having a pressure of 1 kg./cm.^{2}. The droplets of the fuel were captured on smoky glass plates, which were photographed afterwards with a magnification of 50 times. As criteria for the estimation of the quality of atomisation Sauter's average diameter and a newly introduced modulus of atomisation were used.

This investigation has established a direct relation between the quality of atomisation and the injection pressure. It was found that the effect of the injection pressure upon the quality of atomisation is more pronounced in the range of the lower pressures. At equal injection pressures benzine gives a finer atomisation than kerosene. Injection in a counter-stream of air gives better atomisation than injection in calm air.

Effect of Fuel-Air Ratio on Detonation in Petrol Engines. (L. A. Peletier, World Petroleum Congress, Paris, June, 1937. Available as Translation T.M. No. 853.) (55/28 France.)

According to the generally accepted view, detonation is equivalent to the self ignition of the unburnt charge at some period prior to complete (normal) inflammation.

It is well-known that the tendency to detonate is reduced as the mixture strength is increased and the author gives a list of factors which he considers responsible:—

1. Pressure and temperature of unburnt charge at end of compression is reduced on account of the small specific heat ratio of the rich mixture.
2. A further reduction in temperature is due to increased latent heat.
3. Flame speed is reduced and this increases the compression time.
4. Lower flame temperature decreases cylinder wall temperature (especially exhaust valve).

Direct experiment of variation of auto-ignition temperature with mixture strength (limiting compression ratio with engine motored), however, showed that the richer mixtures auto-ignite more readily and the author therefore concludes that the factors 1-4 listed above reverse this natural tendency.

Note—The author apparently neglects any possible effect due to admixture of exhaust with unburnt charge.

The Structure of Lubricating Greases. (A. S. C. Lawrence, J. Inst. Petrol. Tech., Vol. 24, No. 174, April, 1938, pp. 201-20.) (55/29 Great Britain.)

Soap oil systems exist in three forms: True solution, true gel and pseudo gel, which is a paste of micro-crystals. Commercial lubricating greases may be in stage 2 or 3. There is a well-defined temperature of transition from 2 to 3 which depends on the nature of the soap used and upon the pressure of polar substances, such as fatty acid, water or glycerine, which lower it. These greases are not emulsions. Natural greases such as butter and tallow are emulsions in which the dispersion medium is a soft solid. Dispersion of the soap in the oil can be brought about by stirring at any temperature above that of the transition and does not require raising to that of true solution. Formation of gel and pseudo gel are crystallisations and the mechanical properties of the systems are due to the peculiar crystal habit and properties of the separating soap particles. The properties are profoundly modified by small amounts of fatty acid.

Catalysts in Hydrocarbon Chemistry. (E. K. Rideal, J. Inst. Petrol. Tech., Vol. 24, No. 174, April, 1938, pp. 221-4.) (55/30 Great Britain.)

In hydrocarbon chemistry increasing attention is being paid to catalytic processes. It is shown that these can be formulated on a radical mechanism. Homogeneous reactions can be brought about by free radicals and heterogeneous reactions by chemi-absorbed radicals. The energy of activation of such heterogeneous processes is less than one-fourth of the corresponding homogeneous reactions. This permits of lower temperature operation, greater efficiency and greater control. The use of o.p. hydrogen and of deuterium as tools for the elucidation of the mechanism of hydrogenation is briefly indicated.

Effect of Carburation and Manifolding on Fuel Knock Characteristics. (E. Bartholomew, H. Chalk and B. Brewster, Oil Gas J., 13/1/38. J. Inst. Petrol. Tech., Vol. 24, No. 174, April, 1938, pp. 194A-195A.) (55/31 Great Britain.),

The relative knocking tendency of cylinders of a multi-cylinder engine varies with carburation and fuel distribution, provided spark advance and cylinder cooling are uniform. Variations in knocking among the cylinders due to differences in cooling are believed to have been minimised in recent engines. Variations in spark advance create a greater problem, but recently an instrument capable of measuring the ignition advance of each cylinder simultaneously has been devised. This is described and illustrated.

It is apparent that with all the possible variations in carburation, fuel distribution, etc., in engines of the present day, no single set of carburettor and manifold conditions for the laboratory engine should give ratings equal to the average of

ratings obtained on several cars. The development of a correction factor applicable to all types of fuel and capable of direct determination on the engine would be desirable.

Application of the Grignard Reagent to a Study of Mineral Oils. (R. G. Larsen, Ind. and Eng. Chem. (Analytical Edn.), Vol. 19, No. 4, 15/4/38, pp. 195-8.) (55/32 U.S.A.)

During a chemical and electrical study of oil oxidation, a Grignard reagent (methyl magnesium iodide) was applied as an analytical tool with some success. By using apparatus similar to the " Grignard machine " currently in use for elucidation of the structure of organic compounds, procedures have been devised which permit the determination of minute amounts of water in oil, the establishment of an oxygen balance during oil oxidation, and the approximate prediction of oxidation stability by a single test on the original oil.

Ignition Quality of Diesel Fuels. (J. Inst. Petrol. Tech., Vol. 24, No. 173, March, 1938, pp. 176-9.) (55/33 Great Britain.)

The ignition quality of a fuel is a measure of the relative time required for combustion to start after the commencement of injection; the shorter the time the higher the ignition quality.

High ignition quality indicates ease of starting and smoothness of running, but the ignition quality of a fuel is not necessarily an indication of its combustion quality in all types of compression ignition engines. Furthermore, hot-bulb engines have special requirements, as have engines which use spark ignition for heavy oils. No form of test is suitable for rating fuels for these engines except direct tests in the engines themselves.

The routine test described involves the use of reference fuels calibrated by the I.P.T. Diesel Panel, but it should be mentioned that other suitable secondary reference fuels have been employed elsewhere.

Two methods of test have been described in I.P.T. Serial Designation F.O.39 (T). The first method measures the ignition delay directly by means of an indicator. In the second method the intake of the engine is throttled till misfiring occurs. Method I is preferred for routine cetane number determinations but Method II has the special advantage of being readily applicable to a large range of Diesel-engine types and is therefore convenient for making comparisons of fuel ignition quality where special apparatus is not available.

The Problem of Detonation. (M. Serruys, Airc. Eng., Vol. 10, No. 111, May, 1938, pp. 143-151.) (55/34 France.)

Following the usual theory that detonation is essentially auto-ignition of the " rest " gas, the author attempts to draw general conclusions from single cylinder experiments of small power output. (Brake horse-powers are quoted accurate to 1 in 10,000!). The author points out that as many as 17 factors (of which 6 are of major importance) determine the behaviour of the rest gas. There appears great danger that with so many factors almost any experimental result can be explained by adjusting their relative importance. Thus the well-known anti-knock effect of rich mixture is attributed to the smaller explosion pressure reducing the effective compression ratio of the rest gas. Yet both laboratory experiments and the chain reaction theory indicate a lower ignition temperature for the richer mixture.

No details are given of the type of connection employed for the optical indicator and it appears doubtful whether the vibrations shown on the expansion line are true indications of the state of motion of the gas in the engine cylinder.

Electrical Apparatus on Aircraft. (H. Viehmann, E.T.Z., 7/4/38, pp. 361-6. Metropolitan Vickers Electrical Co., Tech. News Bulletin, No. 606, 15/4/38, p. 7.) (55/35 Germany.)

After setting forth the requirements to be satisfied by electrical apparatus to be used on aircraft, the author discusses the special features of the current sources, the aircraft network and the current consuming devices, special reference being made to automatic switches, fuses, navigation lights, ignition systems for the Otto engines and wireless interference suppression. Illustrated with six diagrams and three photographs.

Investigation on Landing Impact of Seaplanes. (A. S. Povitzky, Trans. Scientific Tech. Soc. of Shipbuilding and Engineering, Vol. 2, 1936. Eng. Absts., Vol. 1, No. 2, Section 3, March, 1938, p. 14.) (55/36 U.S.S.R.)

Particulars are given of the methods adopted by the Hydro-Experimental Department of the Central Aero-Hydro-Dynamic Institute when carrying out experiments on seaplanes. Interesting results were obtained from the tests by means of micro-recording instruments at present used by the above department, which include a dynamic tensiometer for synchronous measurement of deflection, an accelograph for overload measurements and a stress recorder for measuring the pressure on the hull skin. Illustrations are given of the various instruments employed in carrying out the experiments. The most interesting instrument is the accelograph which has a range of acceleration from 130 units per second (1 variant) to 250-300 units per second (2 variants); this high acceleration permits the overload stresses produced by outside forces as well as the vibration to be recorded with great accuracy. Overload graphs are given of a seaplane when landing.

The Bristol Metameter. (J. A. Oates, Metropolitan Vickers Electrical Company, Ltd., Tech. News Bulletin, No. 607, 22/4/38, p. 7. Electrical Engineer, 8/4/38, pp. 860-2.) (55/37 Great Britain.)

The author describes the construction and operation of the Bristol Metameter, an instrument for transmitting records of various quantities. The "Impulse" system of telemetering is employed. Contacts in an electrical circuit are repeatedly opened and closed, the opening taking place at uniform time intervals, and the period of closure being governed by the value of the measured quantity. Illustrated with two photographs and three diagrams.

Some Results from Research on Flow Nozzles. (H. S. Bean and S. R. Beitler, Trans. A.S.M.E., Vol. 60, No. 3, April, 1938, pp. 235-44.) (55/38 U.S.A.)

The circumstances which caused the A.S.M.E. special research committee on fluid meters to undertake the present research programme on flow nozzles were recounted in an earlier paper. In that paper many of the committee's arrangements and plans for conducting the research were given. In another paper,* a description was given of the method being used to measure the size and shape of the nozzles.

This present paper which is the third of the series is a progress report presenting the results from various subsidiary tests. There is given a comparison of results from tests using rough and smooth pipe, standard and extra heavy pipe, and clean and deposit coated nozzles. Based upon tests with steam, there is given a comparison of the adiabatic expansion factor ϕ and the "net" expansion factor Y. The results from several groups of pressure gradient tests are pre-

* "Determining Flow Nozzle Contours at National Bureau of Standards," by F. C. Morey, Instruments, Vol. 10, June, 1937, p. 157.

sented, and based upon these results there is given a recommendation on the location of pipe-wall taps.

Reference Tables for Iron-Constantan and Copper-Constantan Thermocouples. (W. F. Roeser and A. I. Dah, Bur. Stan. J. Res., Vol. 20, No. 3, March, 1938, pp. 337-355.) (55/39 U.S.A.)

Tables have been prepared giving corresponding values of temperature and thermal electromotive force at various temperatures from −200 to 1,000°C. for iron-constantan thermocouples. Similar tables from −200 to 400°C. for copper-constantan thermocouples, although not new, have been included for completeness. The temperature-emf relations embodied in these tables are such that (1) each can be reproduced with materials generally and readily available; (2) each is the same (within $\pm\frac{3}{4}$ per cent.) as the temperature-emf relation of a large percentage of such thermocouples of that type now in use; (3) each is near the mean of the extreme limits of the temperature-emf relations for thermocouples of that type; (4) the table for iron-constantan is near the existing table most widely used, while the one for copper-constantan is the one most widely used; and (5) the constantan used with one element to reproduce one table can be used with the other element to reproduce the other table.

This paper also gives (1) average values of the thermal-emf of copper, iron which is generally available, and constantan against platinum, as a guide in selecting materials to yield any specified relation between thermal-emf and temperature for thermocouples of these types and (2) the variations in thermal-emf that might be expected between samples of these materials from the same lot and from different lots.

The Constantin Wind Vane Stabiliser on Aircraft. (J. Mottez, Tech. Aeron., Vol. 29, No. 147, pp. 45-82.) (55/40 France.)

The author investigates mathematically the stability of a given aircraft, both when flown normally and when fitted with a wind vane stabiliser. The results are incorporated in a series of graphs from which the author concludes:—

1. The wind vane stabiliser produces qualitatively the same results as would be obtained by alteration of dihedral or changes in the tail surface. Objectionable aircraft characteristic can thus be remedied in a simple manner without entailing constructional alterations.
2. Combined with the normal wing flaps, the wind vane is very useful in controlling the elevator so as to limit variation in the position of the centre of pressure. Considering its extreme simplicity and reliability the device is thus considered to merit the close attention of aircraft designers.

On the Forces Acting Between Atoms and Ions and the Physical Properties of Matter in Bulk. (J. A. Wasastjerna, Phil. Trans. Roy. Soc., Series A, Vol. 237, No. 774, 7/3/38, pp. 105-31.) (55/41 Great Britain.)

A method is developed according to which it is possible to analyse, by the aid of accessible experimental data, the question of the dependence of the potential energy on the interatomic distance for atoms and ions with closed shells. The results of the analysis have been made the foundation for a theoretical calculation of a number of physical properties of crystals. In many instances the results of the calculations can be compared with experimental data. In other instances information is obtained concerning data, which have previously been entirely unknown or about which great uncertainty has prevailed. Finally, a theoretical interpretation is given to the empirical results.

Natural Frequencies of Uniform Cantilever Beams of Symmetrical Cross Section. (L. S. Jacobsen, J. App. Mech., Vol. 5, No. 1, March, 1938, pp. A1-6.) (55/42 U.S.A.)

(*a*) The paper contains a deduction of the general frequency equation of cantilever beams. From this general equation, which is rather complicated, a number of simpler equations have been deduced, relating to frequencies of beams in which as many as four of the six independent variables have been neglected. It is shown that *considerable simplification results if the effect due to rotatory inertia is neglected.*

(*b*) An example of the influence of an elastically yielding ground on the first six mode periods of a building shows the *gradual transformation of the second mode period of the cantilever into the fundamental mode period of the free beam,* the third of the cantilever into the second of the free beam, etc.

(*c*) A general solution of the first four mode periods of the rigidly built-in cantilever is given in tabular form. *The effect of shear increases with the order of the mode, so that for high mode frequencies a consideration of shear alone gives good results unless the beams are very slender indeed.*

(*d*) The influence of *shearing or torsional elastic yielding* of the ground on the first five mode periods of a beam subjected to translational shear or to torsional shear is given by a family of curves. The curves show *the same type of transformation of second mode of cantilever to fundamental mode of free beam,* etc., as discussed in the building example.

Engineering Radiography. (E. A. W. Mueller, Siemens Revue, Vol. 3, 1937, No. 5, pp. 161-7. Metropolitan Vickers Electrical Co., Tech. News Bulletin, No. 606, 15/4/1938, p. 6.) (55/43 Great Britain.)

A brief survey is given of the applications of radiography to welded work, forgings, castings and other products. Several types of X-Ray industrial testing are described.

Illustrated with various photographs and diagrams.

A Method of Calculating Intricate Statical Indeterminable Systems. (P. A. Minjaev, Trans. Scientific Tech. Soc. of Shipbuilding and Engineering, U.S.S.R., Vol. 2, 1936. Eng. Absts., Vol. 1, No. 2, Section 3, March, 1938, p. 14.) (55/44 U.S.S.R.)

The usual method of calculation for a statical indeterminable system is based on the assumption that the unknown elements are independent and variable. This may be considered as arriving at an informal solution of the system. A general method of solution may be developed by treating the unknown forces as functions independent of each other, and considering the potential energy as a component function of them. This permits deriving a system of equations with a gradual reduction of the numbers of the unknown by application of the principle of least work. The last equation will contain only one unknown element, thus permitting its value to be determined; the general solution may be then gradually obtained by the method of substitution. Where there are a large number of unknown elements the calculation may be simplified by dividing the system into parts and by the application of the above method to each separate part.

Fatigue Tests of Strengthened Flanges in Welded Tension Bars and Girders. (O. Graf, Z.V.D.I., Vol. 82, 12/2/38, pp. 158-60. Eng. Absts., Vol. 1, No. 3, Section 1, March, 1938, p. 33.) (55/45 Germany.)

The author describes tests of the joint in a 5½in. by ¾in. tension-bar having welded covers, the ends of which were diminished in width and thickness; and also when provided with rectangular covers uniform in width and thickness, having the transverse end welding fillet ground off to a smooth finish. Under repetition loading with a minimum constant load ranging from 0.3 ton to 0.6 ton per sq. in.,

the former type revealed a fatigue strength of 8.8 tons per sq. in. and the latter of 10.7 tons per sq. in. A test of a 12in. by 5in. joist, having a fusion-welded joint in which the flanges were splayed at an angle of 45 degrees, revealed a fatigue strength of 11.3 tons per sq. in. An equal strength was developed when the joint was made with rectangular flange-covers, the welding fillets being machined as described above.

A New Method Based Upon the Principle of Least Work for the Calculation of Box Girders Subject to Torsion. (C. Minelli, Richerche de Ingegneria, Vol. 5, November-December, 1937, pp. 155-61. Eng. Absts., Vol. 1, No. 3, Section 1, March, 1938, p. 33.) (55/46 Italy.)

The author explains briefly a method of calculating the conditions of strain in complex elastic systems by reference to the principle of least work, enabling the conditions of stress to be induced immediately therefrom. Developing a long succession of equations, he applies this method to the design of box girders such as occur in aircraft construction, and discusses four different problems according to the conditions of end fixation, the presence or absence of internal diaphragms, and the mode of application of torsional loads.

Force Distribution in Riveted Connections of Constant Cross Sections Under Tensile Loads. (L.F.F., Vol. 15, 20/1/38, pp. 41-7. Eng. Absts., Vol. 1, No. 3, Section 1, March, 1938, pp. 33.) (55-47 Germany.)

The author develops a method for the approximate determination of the force distribution in simple butt straps of constant cross section up to the tensile breaking load. The expressions which he develops permit the determination of the displacements of the straps for both elastic and plastic deformation of the rivets. In order to simplify the calculations he replaces the rivets by an ideal connecting layer between the surfaces and formulates an equation for the total displacement at any point in the connection, which is made up by the displacement in shear within the layer and the difference of the displacements in tension, integrated up to the point under consideration, of the plates connected.

The author describes tests on the displacements taking place in double-shear connections, each consisting of ten duralumin rivets disposed in line with the pull and connecting plates of different thicknesses, and also tests made with various types of single-rivet connections. An analysis of the results indicated good agreement with those calculated, and the author concludes that at small loadings the force-distribution in the connection is markedly non-uniform. If the loads are increased up to the breaking point, however, greater uniformity is obtained, owing to the permanent deformation which is set up in the end rivets.

Detection of Electric Welding Faults by X-Rays. (J. E. de Graaf, Metropolitan Vickers Electrical Company, Ltd., Tech. News Bulletin, No. 607, 22/4/38, p. 13. Welding Industry, April, 1938, pp. 93-6.) (55/48 Great Britain.)

This is the concluding section of the article which reviews the types of fault that can be found in electrically welded steel parts by means of X-Ray examination. In this present number there are two pages of characteristic X-Ray photographs which are fully discussed. The conclusion is that, when faults have fully developed characteristics, it is generally possible to give an interpretation by the X-Ray method. Illustrated with 21 photographs and three diagrams.

Ordinary Fracture, Time Limit Fracture, and Fatigue Fracture (Appearance of Fracture Under Tension Bending and Torsion). (A. Thum, Forschung, Vol. 9, No. 2, March-April, 1938, pp. 57-67.) (55/49 Germany.)

All constructional materials give rise to a variety of fracture phenomena, both in ordinary practice and in the testing laboratory. In order to obtain from them knowledge useful for design purposes, it is necessary to recognise the typical

appearance of the different fractures, to determine which general laws apply, and to investigate the internal mechanism of the failure. At the same time, special consideration must be given to the shape of the fractured part, the nature of the surface, and the material itself. The present research is intended to provide the fundamentals. It is chiefly restricted to rolled steel and cast iron.

Optical Investigation on Three-Dimensional Stress Conditions (Convergent Light). (R. Hiltscher, Forschung, Vol 9, No. 2, March-April, 1938, pp. 91-103.) (55/50 Germany.)

The " solidification method " developed by G. Oppel for the first time offered the possibility of investigating three-dimensional stress conditions with the aid of polarised light. Oppel's analyses were confined to the special cases of symmetrical stresses, the deformed test specimen being cut up in slices perpendicular to one of the three principal normal stresses. The other two principal normal stresses lie in the plane of the slice, so that the problem is reduced to investigation of two-dimensional stress conditions. The direction of one of the principal normal stresses must therefore be known beforehand, while it is doubtful which of the three principal shear stresses are measured in the plane. An optical method was therefore evolved which above all determines the directions of the three principal normal stresses. The investigation thereby becomes independent of the direction of the cut, and any unsymmetrical three-dimensional stress problems may be handled. As an example the method is applied to a portion of a crankshaft.

The Crystalline Structure of Steel at Fracture. (H. J. Gough and W. A. Wood, Proc. Roy. Soc., Series A, Vol. 165, No. 922, 14/4/38, pp. 358-71.) (55/51 Great Britain.)

The stability of the atomic arrangement in the metal is the result of equilibrium between the positive ions and the surrounding electron distribution. Permanent deformation of the metal produces, in the first place, a process of grain dislocation and fragmentation leading to a structure consisting entirely of a mass of crystallites having a limiting size and completely random orientation. But the attainment of this condition is not the criterion of fracture; in fact, although it is doubtful if the metal is really " strengthened " by such cold-working, it can certainly withstand, without plastic deformation, a greater strain or range of strain than in its initial state. The investigation shows that the stage when fracture is imminent is approached only after the structure has become completely fragmented. The experiments have clearly demonstrated the progressive deterioration in the regularity of the atomic structure and electron distribution and, therefore, a disturbance of the equilibrium of the structure. This produces localised regions of weakness at which fracture can be initiated under the action of external forces whose magnitude would appear to be quite inadequate if the material were homogeneous and possessed the full theoretical strength.

Twisting Failure of Centrally Loaded Open-Section Columns in the Elastic Range. (Kappus, R., L.F.F., Vol. 14, No. 9, 20/9/37, pp. 444-57. Available as Translation T.M. 851.) (55/52 Germany.)

The buckling of centrally loaded columns of open section is always accompanied by a twist if the cross section discloses neither axial nor point symmetry. There are three such axes of twist and consequently three different critical compressive stresses (twisting failure stresses). With point symmetry of the cross section the three critical compressive stresses are given in two Euler stresses for (twist-free) buckling in direction of the two principal axes of inertia and one twisting failure stress for twisting about an axis of rotation passing through the centre of gravity. With simple cross-section symmetry, it finally affords one Euler stress for buckling in direction of the axis of symmetry and two twisting failure stresses for twisting about two axes of rotation in the plane of symmetry. The thicker

the wall and the greater the length of the columns the more the effect of the twist is neutralised, as the distance between centre of rotation and centre of gravity continues to increase until, finally, the observed buckling is practically free from twist.

Twisting of Thin-Walled Columns Perfectly Restrained at One End. (Lazzarino, L., L'Aerotecnica, Vol. 17, No. 10, Oct., 1937, pp. 850-61. Available as Translation T.M. 854.) (55/53 Italy.)

Proceeding from the basic assumptions of the Batho-Bredt theory on twisting failure of thin-walled columns, the discrepancies most frequently encountered are analysed. A generalised approximate method is suggested for the determination of the disturbances in the stress condition of the column, induced by the constrained wrinkling in one of the end sections.

Photoelastic Determination of Stresses Around a Circular Inclusion in Rubber. (W. E. Thibodean and L. A. Wood, Bur. Stan. J. Res., Vol. 20, No. 3, March, 1938, pp. 393-409.) (55/54 U.S.A.)

Analysis is made of the stresses around a rigid circular inclusion with cemented boundary in a rubber sheet which is under simple tension at a distance from the inclusion. The analysis is performed by the photoelastic method, in which data are obtained from observations of the changes produced in a beam of polarised light passing through the transparent model. The fundamental principles of the method and a detailed account of their application are given. The possibilities of the use of rubber as a model material are demonstrated. The stress-optical coefficient of a certain soft vulcanised rubber compound is found to be 2,030 brewsters.* This is in agreement with the results of previous work. The maximum stresses near the boundary of the disk are found to be about 50 per cent. greater than the average applied stress. The experimental results are compared with those given by a theoretical treatment of this problem, and quite satisfactory agreement is obtained.

On the Influence of Chromium on the Oxidisability of Tungsten at High Temperatures. (S. Isida and H. Asada, Aer. Res. Inst., Tokyo, Report No. 161, April, 1938.) (55/55 Japan.)

Alloys of chromium and tungsten were prepared by the thermite process and the melting point, microscopic structure, X-Ray analysis and hardness were determined over a range of compositions. It appears that the oxidisability of tungsten in air (900°C.) is markedly reduced by the addition of 13 per cent. of chromium.

A Method of Measuring the Thermal Conductivity of Fluids. (H. Pfriem, Z.V.D.I., Vol. 82, 15/1/38, pp. 71-2. Eng. Absts., Vol. 1, No. 3, Section 2, March, 1938, p. 47.) (55/56 Germany.)

The author observes that, with the known fixed methods of measuring the thermal conductivity of fluids, the heat-loss due to convection currents presents an important difficulty. Moreover, the methods are complicated by the necessity of adopting means for counteracting heat-losses. He describes a simple method in which a very thin wire, electrically heated, is stretched vertically in the fluid. The calculation of the temperature field is based upon the known equation for heat-conductivity in cylindrical temperature fields. The author discusses briefly the theory upon which this method of measurement is based and gives the principal formulæ from which the results are calculated.

* One brewster $= 10^{-13}$ cm^2/dyne.

The Heat Conductivity of a Spherical Packing in a Gas Current. (G. Kling, Forschung, Vol. 9, No. 2, March-April, 1938, pp. 82-90.) (55/57 Germany.)

The heat conductivity of ball packings increases considerably due to the convection of the contained gas. The influence of the gas flow through the interstices is investigated for the case that the heat flow is in a direction perpendicular to an enforced gas flow.

Investigation of Wave Phenomena on Models Using Ultra Sonic Waves. (S. Kretochner and S. Rshevkin, Technical Physics, U.S.S.R., Vol. 4, No. 11-12, Nov.-Dec., 1937, pp. 1004-1019.) (55/58 U.S.S.R.)

Plane waves of the order of $\lambda = 1$ mm. were generated in an oil bath and illuminated at right angles by a parallel beam of light. The resultant wave patterns were examined by the Toeppler " Schlieren " method, a Kerr cell providing an effective stroboscope. Photographs are given showing a number of simple reflection, diffraction and interference effects.

The author applied the new technique to the study of the acoustical properties of irregular wall surfaces and predict the transition frequency from regular reflection to scattering.

The work is being continued.

Magnetic Method for Measuring the Thickness of Non-Magnetic Coatings on Iron and Steel. (A. Brenner, Bur. Stan. J. Res., Vol. 20, No. 3, March, 1938, pp. 357-68.) (55/59 U.S.A.)

A non-destructive, magnetic method is described for measuring the thickness of non-magnetic coatings on steel. The instrument used is similar to that previously described for measuring nickel coatings on non-magnetic base metals. The present method depends on the decrease in the attraction of a permanent magnet for steel when the two are separated by a non-magnetic coating.

Measurements on commercial coatings of which the actual thicknesses were determined by standard methods yielded results that were accurate to ± 10 per cent. for most coatings. The results were about 25 per cent. low for hot-dipped tin coatings, which are only about 0.0001in. thick.

Because nickel is less magnetic than steel, the thickness of nickel coatings on steel can be measured by this method, using a suitable calibration curve.

A Method for the Investigation of Upper Air Phenomena and its Application to Radio Meteorography. (H. Diamond, W. S. Hinman, Jr., and F. W. Dunmore, Bur. Stan. J. Res., Vol. 20, No. 3, March, 1938, pp. 369-92.) (55/60 U.S.A.)

Experimental work conducted for the U.S. Navy Department on the development of a radio meteorograph for sending down from unmanned balloons information on upper-air pressures, temperatures and humidities has led to radio methods applicable to the study of a large class of upper-air phenomena. The miniature transmitter sent aloft on the small balloon employs an ultra high-frequency oscillator and a modulating oscillator; the frequency of the latter is controlled by resistors connected in its grid circuit. These may be ordinary resistors mechanically varied by instruments responding to the phenomena being investigated, or special devices the electrical resistances of which vary with the phenomena. The modulation frequency is thus a measure of the phenomenon studied. Several phenomena may be measured successively, the corresponding resistors being switched into circuit in sequence by an air-pressure-driven switching unit. This unit also serves for indicating the balloon altitude. At the ground receiving station, a graphic frequency recorder, connected in the receiving set output, provides an automatic chart of the variation of the phenomena with altitude. The availability of a modulated carrier wave during the complete ascent allows of

tracking the balloon for determining its azimuthal direction and distance from the receiving station—data required in measuring the direction and velocity of winds in the upper air.

Constants of Fixed Antennæ on Aircraft. (G. L. Haller, Proc. Inst. Rad. Eng., Vol. 26, No. 4, April, 1938, pp. 415-20.) (55/61 U.S.A.)

This paper presents the resistance and reactance characteristics of various fixed antennæ on two types of modern aircraft, one a two-place low-wing metal military aeroplane of the attack type and the other a large mid-wing metal military aeroplane of the bombardment type, whose dimensions are comparable to those of modern commercial transport aeroplanes. A frequency range of from three to eight megacycles is covered in all cases and in some cases this range is extended. A description of the measuring equipment and method is included.

Water Purification by Ozone. (Metropolitan Vickers Electrical Co., Ltd., Tech. News Bulletin, No. 608, 29/4/38, p. 5. Electrician, 22/4/38, p. 511.) (55/62 Great Britain.)

The desirability of water purification in various cases is discussed, and the "Ozonair" system of treatment by electrically generated ozone is described. This is compared with the chlorination process.

Illustrated with 1 diagram.

Aerial Survey in Exploration Work. (B. Scherpbier, J. Inst. Petrol Tech., Vol. 24, No. 174, April, 1938, pp. 225-32.) (55/63 Great Britain.)

Aerial photography has proved to be of great value for petroleum exploration work, especially in remote countries. Photogrammetric cameras have advantages over photographic ones, also when surveying undeveloped countries, because their use entails less ground control.

By applying aerial triangulation the ground control can be reduced to the determination of ground bases 100-200 km. apart.

Aerial survey enables the exploration geologist, before entering the area to be explored, to have already available a topographical map, which very often even contains geological information derived from the photographs.

REVIEWS.

Martin's Air Navigation.

By C. W. Martin. 2nd Edition, 1938. Eversley Press. Price 25/-.

The popularity of Martin's Air Navigation has justified a second edition. The first edition was reviewed in the Journal of the Royal Aeronautical Society of January, 1937, to which the reader is referred.

There are several additions in the new book. The index is very welcome. The subject matter is better arranged. Most welcome of all is the additional detail in the chapter on Meteorology. This chapter is now excellent, and *anyone* who desires to learn something of this interesting subject is advised to refer to this book, and particularly to the accounts of ice formation, fronts and forecasting.

Only one paragraph is unpleasant. On p. 244, we find:—

> "A comparison of English, French, German and Norwegian Synoptic charts for the same hour will very often reveal that the fronts have been inserted by the meteorologists of the different nations in different places. Unless the fronts are well defined, it is impossible to obtain from any specialist in Frontology in order of importance, a list of points to study when attempting to identify a front."

The above is true enough. There are good and bad meteorologists. Yet Mr. Martin's remarks seem rather out of place in a book of this type.

Apart from these small criticisms, one can genuinely recommend the book, as giving the clearest account of air navigation, which has yet been written.

The 1/500,000 Aviation Map of Great Britain.

Price on paper 2/- per sheet, on linen, mounted, 4/6 per sheet.

Pilots of aircraft, unless equipped with wireless, rely almost entirely on map reading for air navigation. For this purpose, air maps must be accurate and sufficient. They must show all landmarks which are clearly visible from the air. They must also omit detail, which, though important to the soldier, sailor, motorist, politician or archæologist, is of no consequence to the pilot. The air maps of this country have slowly been evolved on this principle. In successive editions of the 4-mile and 10-mile Aviation maps, we have seen county boundaries, names of villages and sites of battles (usually including the date, which looks like a spot height) slowly and unwillingly vanish. Even General Roy's base, so beloved by cartographers, has gone.

Until this year, the 4-mile map of Great Britain was rightly regarded as the best air map in the world; and those who have flown abroad will appreciate the infinite superiority of the British Ordnance Survey maps.

The 4-mile map has, however, one disadvantage. On a moderately long flight, too many sheets are required. A compromise between the detail of the 4-mile map and the area covered by the 10-mile map was indicated.

The result was the production of the 1/500,000 aviation map, which is based on a quarter sheet of the International 1/1,000,000 series. The modified polyconic projection is used, so that scale and bearings are very accurate over the whole sheet. On this map, where nothing of importance is visible from the air, nothing is shown. All villages and minor roads are omitted. Often a town is shown, but the name is not given. The result is that the essentials—railways, rivers and aerodromes—stand out very clearly. The detail of the 4-mile map is inevitably lacking; it would have been impossible to include it on this small scale map. But the essentials, which an experienced pilot requires are given, and the map

covers a reasonably large area. Possibly the area might have been further increased by using larger sheets covering 6° of longitude instead of 3°, and retaining the generous overlap of 30ft.

If pilots still lose their way, it is not the fault of the ordnance survey. Possibly the psalmist sums it up:—

"They have eyes and see not."

ASTRONOMICAL NAVIGATION MADE EASY.

By G. W. Ferguson. (Pitman's) 5/-. 1938.

Mr. Ferguson has produced a small book, which attempts to explain the principles of astronomical navigation, and the mathematics required for the calculation of position lines, etc.

The first part of the book deals with spherical trigonometry. The order and arrangement of this might be improved and clarified. Unimportant formulæ, such as:—

$$\sin \text{amplitude} = \sin \text{declination} \times \sec \text{latitude}$$

are given, and yet the author mentions on p. 13 that the amplitude may be readily obtained from Norie's tables. On p. 17 we find that the quantities R.A., R., E., Dec., H.A. and R.A.M. are not defined, which for an elementary book is inexplicable.

The author's account of calculating zenith distance and position lines is better, and especially the derivation of latitude from ex-meridian observations, but the fix obtained on p. 55 from a single position line is grossly inaccurate.

There follows an account of logarithms. Should the student of navigation wish to understand this important aid to calculation he is advised to read "Martin's Air Navigation," where these things are made easy.

The author hardly attaches sufficient importance to the "Air Almanac," which has been published at the initiative of the Air Ministry to simplify the working of astronomical sights. The excellent Pole Star table in the Air Almanac is not even mentioned.

The book is, however, worth reading for the account of Time on pp. 47-49, and for the excellent conversion table of "time to arc and arc to time," on p. 65.

THE CHOSEN INSTRUMENT.

Norman MacMillan, John Lane, London, 1938. Price 5/- net.

Discussing the position of Belgium and that of the great air powers, Captain Norman MacMillan, on p. 31 of his book, says "The cockpit of Europe assumes a new significance from the cockpit of an aeroplane."

The Chosen Instrument is entirely concerned with the new orientation of international relationships which has been brought about by the rapidly increasing power of military aircraft, and as Captain MacMillan consistently hammers home in as measured terms as he can, this new orientation is to the disadvantage of Great Britain and to the advantage of Germany.

It is only by stretching political and other imaginations to the limit that we can believe the political and military heads of this country are not fully aware of the situation which has developed, or that the rulers of other countries are not acutely aware of it too. Captain MacMillan's book should be read and re-read by everyone who has the slightest sense of responsibility in this country's welfare, so that a developed public opinion can insist on the true position being made clear, as clear as the author, indeed, writes it.

One hears from politicians the well worn appeal "don't shoot the man at the piano, he's doing his best." Nothing is more fatal than refraining from criticism on the grounds it may hamper the man who is carrying on the job. If he is carrying it on well, the result is so obvious that he will not be criticised. He is criticised because of the uneasiness he has created by his own work or method, and he deserves most thoroughly all the criticism he gets.

That is the position of British military aviation at present. Uneasiness has spread among all, whether they are concerned directly with aviation or not, that all is not right in the air defence of the country, and as a palliative scheme A, scheme B, scheme C and the rest are put into operation to increase the number of aeroplanes from 1,750 to 2,500, from 2,500 to 3,000 and so on. The safety of Great Britain at that rate can only be assured when scheme Z is put into force, though it would have been better to use numbers instead of letters. There would be more schemes possible.

"To-day," says the author, "we need a man who is prepared to sweep the skies as Nelson swept the seas."

To-morrow, if things progress as they are doing so now, British housewives will be sweeping up the debris of their homes to make them tidy for their conquerors.

ENGINEERING MECHANICS. Vol. 1, Statics. Vol. 2, Dynamics. S. Timoshenko and D. N. Young. McGraw Hill Publishing Co., Ltd., London and New York, 1937. 15/- each volume.

The names of Professors Timoshenko and Young on the title page of a book on Engineering Mechanics are, in themselves, a sufficient guarantee of the accuracy and interest of its contents.

It is most refreshing to read the second sentence in the preface to these two volumes. "The demand from industry is more and more for young men who are soundly grounded on their fundamental subjects, rather than for those with specialised training." It is followed by "The industrial engineer is continually being confronted by new problems which do not always yield to routine methods of solution."

Those sentences are almost, nowadays, like "manna" in the engineering desert. A sound grounding in fundamental subjects is what is definitely lacking in many directions, and it particularly applies to many more text books which are appearing on aeronautical engineering, in which the authors actually boast how they have managed to explain how to design an aeroplane with no or very little knowledge of mathematics, and as far as one can gather, none at all of aircraft materials or workshop practice. There is an aeroplane spar, apply formula 82 on page 273 to it!

These two volumes are a welcome set-back to this dangerous trend of specialisation before generalisation. The reviewer is of the opinion that no one should be allowed to design an aeroplane structure unless he is perfectly capable, if called upon, to design any other engineering structure from first principles, whether it is a suspension bridge, or a sky scraper, once he has been given the loads which may bear upon them.

In Chapter I the principles of statics are given, followed by chapters on concurrent and parallel forces in a plane and the general case of forces in a plane. The following three chapters deal with forces in space and the last chapter with the important subject, the Principle of Virtual Displacements. In this last chapter Stevinus's very astute argument on the principle of the inclined plane is given, an argument which is well worth studying closely if only as indicating a method of reasoning which may be more widely applied than it usually is. This chapter is a very thorough explanation of the Principle of Virtual Displacements, a principle which is of very great value in many problems. Throughout the whole volume are many illustrative and worked out examples which should be invaluable to the student.

Volume II on Dynamics begins with a chapter on the Kinematics of a Particle, followed by one on the Principles of Dynamics, and chapters on Rectilinear Translation and Curvilinear Translation. Chapter V considers the rotation of a rigid body about a fixed axis, Chapter VI the plane motion of rigid bodies and Chapter VII relative motion. One specially recommends these last three chapters,

and in particular Chapter V to any aeronautical engineering student as worthy of close study. The final chapter on relative motion deals with another aspect of engineering problems in a very excellent way, despite its comparative brevity. Like Vol. I, Vol. II contains many extremely useful worked out examples to illustrate the text.

The authors' work throughout is in gravitational units, and though on page 29 they are careful to explain the meaning of the word " mass," and on the following page weight, they are not so careful in the use of the terms. A new expression to the reviewer is the *gee-pound*, the alternative name of the slug, and perhaps not quite so repulsive.

With reference to the worked out examples the authors state in their preface " Two of the most valuable aids in checking the solution of a problem are the dimensional check and the consideration of certain limiting cases as logical extremes." The volumes would be even more valuable than they are if space—even a whole chapter—were given to the theory of dimensions, one of the major weapons of attack in the hands of the skilled engineer.

Criticism does not mean there are serious defects in either of the volumes. They are first class and are both to be thoroughly recommended.

ROYAL AIR FORCE AND AIR FORCES OF THE BRITISH EMPIRE YEAR BOOK, 1938. Compiled by Leonard Bridgman. Edited and published by Squadron Leader C. G. Burge, O.B.E., R.A.F., 5/- net.

All profits from this new Year Book go to the benefit of the R.A.F. Benevolent Fund.

This excellently illustrated and written volume can be thoroughly recommended to all those who are interested in the work of the Royal Air Force, its organisation and its machines, and those of the Air Forces of the British Empire. It begins with an article on The Role of the Royal Air Force, giving concisely but adequately, the organisation methods of air defence, the functions of the various commands, bomber control training, and so on. It is followed by a detailed account of the Air Estimates for 1938-39, already increased by the force of circumstances, and an excellent summary of operations at home and overseas in 1937. This chapter is well worth studying for the examples it gives of air action, which obtained results quickly and with negligible casualties, which certainly could not have been obtained as effectively, rapidly and cheaply by any other way. Here is recorded the work of the Anti-Piracy Patrol in the Mediterranean, the assistance of the R.A.F. to Brigadier-General and Mrs. Lewin, the escort to Potash convoys between the Dead Sea and Jerusalem, against armed gangs and the Waziristan operations, indicative of the wide and often romantic activities of the Royal Air Force. Excellent short histories of the R.A.F. squadrons, with their badges, several a wide variety in their motives and unit badges. No. 4 squadron has " a sun in splendour, divided per bend by a flash of lightning "; No. 28, " in front of a demi-Pegasus a fasces "; No. 36 (Torpedo-Bomber) " an eagle, wings elevated, perched on a torpedo "; and as a final quotation, No. 151 (Fighter) Squadron " on a hurt, an owl *affrontée*, wings elevated, alighting on a seax." It is comforting to know that No. 151 (Fighter) Squadron has a seax upon which to alight. The Fleet Air Arm, Air Forces of the British Empire, and such particulars as may be given, of service aircraft and a useful diary, complete a volume which deserves a wide sale.

THE FOCKE HELICOPTER.*

H. Focke.

Luftwissen Vol. 5, No. 2, February, 1938, pp. 33-39. Translated by W. J. Stern, A.R.C.S.

The Focke helicopter presents the first successful solution of a problem which has occupied aeronautical science for a considerable time. Details of the record flights carried out last year caused a world sensation and with further development it is not too much to hope that this new type will open up fresh fields which up to now remained closed to orthodox aircraft.

At our request, Professor Focke has supplied us with the following notes for publication. The fundamental consideration which guided him in his work are dealt with in detail together with the preliminary work and experiments which led to the final success.

The Editor.

(see also Luftwissen Vol. 3, 1936, Nos. 5 and 8).

There is no doubt that a zero translational speed together with vertical start and landing presented ideals which up to now were impossible to realise. The power driven glider or in other words orthodox aircraft depend, by their very nature, on relative wind both for lift and control. This type of aircraft started its all-conquering career over 30 years ago and owed its immediate success over dynamic rivals to its inherent constructional simplicity. The future line of development appeared clearly marked and it is significant that although there has been very great improvement in performance, no fundamental changes in principle have been made during this whole period.

In a way the early successes of 1907 and 1909 were a hindrance since all the work was concentrated on developing the glider and other methods of attacking the problem were shelved and forgotten. It took 30 years to realise that a successful practical realisation of one solution does not prove that an alternative solution is necessarily useless.

It is of course understandable that after the first successes with the power driven glider, designers would be loathe to experiment with alternative solutions and that the fundamental drawbacks of the first solution would be overlooked. At the present moment we know exactly the shortcomings of our orthodox aircraft and take corresponding measures to remedy these as far as is compatible with the fundamental limitations of the design. This is the correct attitude for the present. We must, however, not overlook that if we wish to widen these limits in the future, improvements of detail will no longer suffice and that new fields will only be conquered if we retrace our steps and start afresh on new principles.

If the problem is put to us to render our aircraft independent of forward speed, there is only one possible solution; the lifting surface must be given an inherent motion relative to the air independent of the translation of the aircraft as a whole. This motion must be simple and reliable. Oscillating wings (flapping flight) or articulated paddle wheels may be dismissed in view of the fact that we already possess a mechanism which fulfils the two desiderata of simplicity and reliability to a much greater extent, *i.e.*, the propeller.

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* Published by kind permission of Professor Focke, the editor of *Luftwissen*, and the Air Ministry.

The use of a vertical propeller to produce lift is very old, at any rate in theory. Leonardo da Vinci drew sketches of such helicopters. Quite recently the question of the lifting propeller has come very much to the fore and that for two reasons. First of all aeronautics has now advanced to the stage where there exists a definite demand for a type of aircraft which can start and land in a confined space. To some extent the catapult start of orthodox aircraft attempts to do this, but landing in a confined space still presents great difficulties. The operation of so-called " feeder " services working in conjunction with fast air lines, or civil aviators flying over mountainous country or in the colonies, or again those engaged in aerial survey work or wireless research all clamour for a type of aircraft with very short starting or landing run, very steep angles of ascent and descent and control at very low translational speeds. However much we should like to shirk the issue, it is obvious that as long as civil aviation is tied to the present type of aircraft which require large aerodromes for starting and landing, flying can never become very general. An efficient helicopter would meet all these demands and, by making roof and garden landings possible, it would supply a tremendous impetus to civil aviation.

The second reason why the problem of the helicopter has recently come to the fore is the fact that the Cierva Autogiro has given a practical demonstration of the reliability of a large rotating screw working as a lifting device. True, the Cierva Autogiro is not a helicopter, it can neither rise vertically nor land vertically nor hover, since the lifting screw in this case autorotates and is not engine driven. The Cierva Autogiro requires for its action a normal engine propeller which drags the apparatus through the air and it is this motion which causes the rotation of the blade. Nevertheless the Cierva Autogiro presents an interesting intermediate solution and by its mere presence initiated theoretical investigations which otherwise would probably not have been undertaken for some time. The British aeronautical authorities when approached for an airworthiness certificate for the Cierva Autogiro caused aerodynamic experts like Glauert and Locke to elucidate numerically the peculiar phenomenon of autorotation of the Cierva rotor when subjected to the relative wind at a comparatively small angle of incidence.

The Glauert-Locke method of calculation can be applied with small modification to the case of small translational speed of the apparatus and served as a theoretical basis for the design of our helicopter.

As far as concerns practical results already obtained by others prior to the start of my own work in 1932, the following performances were claimed officially or semi-officially by Pescara (France), d'Askanio (Italy) and Oehmichen (France).

Distance approximately 1 km.
Duration about 10 minutes.
Height approximately 18 m.

No information as to the aerodynamical characteristics of these experimental models was available and the machines were evidently not capable of sustained practical flight. When approaching the subject 5 years ago, it would thus not have been worth while to design another similar type and be satisfied with beating these records by a few metres in height and a few hundred metres in distance. What was wanted was a different type, something capable of actually flying in the true sense of the word, even if only an experimental machine. The only way to reach this goal was to use all our theoretical and technical experience. The ideas of the inventor may be good and speculations may be useful, but better results are usually obtained if the problem is first clarified and then put on a mechanically sound basis. To clarify the problem we must first of all be quite clear what essential requirements our proposed solution must meet in order to be a practical proposition. These requirements, in order of importance, are the following:

1. Safe Landing in Case of Engine Failure.

No helicopter had so far satisfied this condition, although in orthodox aircraft this requirement was obviously considered essential from the start. The possibility of setting the lifting rotor into autorotation during the descent and thus reducing the rate of fall had been pointed out theoretically long before Cierva gave a practical demonstration of autorotation with his type of aircraft. The change over from power driven to autorotation necessitates, however, a reduction in the angle of blade incidence of the helicopter rotor and this can only be brought about by some mechanical control. Although a blade angle control necessarily entails a certain amount of complication, it is essential that it be incorporated before a helicopter can be seriously considered. Any design which cannot land safely in case of engine or gear failure is clearly useless.

2. Control and Stability.

The helicopter must be under control under all flying conditions including hovering, without requiring a pilot of exceptional ability. Even better would be statical stability about all three axes and finally dynamical stability should be aimed at. Up to now, the stability of those helicopters which had actually flown had proved unsatisfactory. According to general reports, it has only been possible to keep these machines in their correct position by a continuous operation of the rudder. Moreover these control motions had to be, in all directions, very exact and had moreover often to be applied almost instantaneously. It is true that some other designs are stated to have been stable, without, however, any proof accompanying this statement. Moreover all these designs were subsequently given up for some reason or other and Kármán's pessimistic predictions led many investigators to suppose that it would prove impossible to keep a helicopter in the air for any length of time.

3. General Reliability.

As previous helicopters had only flown for periods reckoned in minutes, the question of reliability of this type of aircraft has scarcely arisen so far. There is no reason why the rigid parts of the helicopter should be less reliable than the fuselage of orthodox aircraft. The rotary parts (rotor and gears) must be made at least as reliable as the engine. This necessarily implies that the general or overall reliability of a helicopter must be less than that of a fixed wing aircraft. Provided, however, that safety in landing is assured in the case of either gear or engine failure (autorotation of rotor), the practical utility of the helicopter is assured.

4. Pilotage.

The technical side of any new problem necessarily only covers a part of the total. Equally or perhaps even more important for the ultimate success is the capacity of the pilot entrusted with flying the experimental model. It is most important that the task of the pilot be rendered as easy as possible and for this reason the controls of the helicopter should resemble as far as possible those already existing on orthodox aircraft. Any extra controls which may be required should be as few and simple as possible.

5. Performance.

The performance of the experimental model must be reasonable. It would obviously be absurd to expect from the start a performance equalling that of the best orthodox aircraft, and in return for slow speed performance we must be ready to make some sacrifice. A helicopter only capable of hovering would, however, be of very restricted value. We must therefore insist on a translational speed which is at least of the same order as that of orthodox aircraft.

6. Maintenance.

A new type of aircraft like a helicopter will obviously require a specially trained crew for its proper maintenance. The design should, however, be such that the fuselage requires no more looking after than a normal type and that the rotary gear will not be any more exacting than a normal engine in order to keep it in efficient condition. If this is borne in mind from the start, the maintenance of the helicopter should present no practical difficulties.

If we consider the above desiderata which our helicopter design must fulfil, we come to the conclusion that success cannot possibly come by some single revolutionary patent but that the only possible approach to the problem will be the following:

All the various requirements considered as necessary must be studied equally fully and all must be incorporated in the final design. Some of these requirements, such as those associated with stability, will necessitate lengthy calculations and are predominantly theoretical. Others, such as simple manipulation and control, are essentially of a practical kind. Midway between these two extremes we have to deal with the very difficult questions of design and engine/rotor installation.

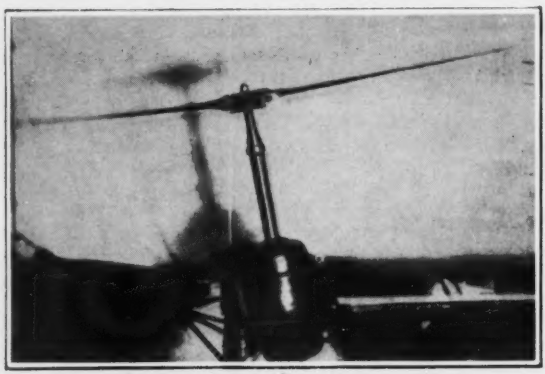


Fig. 1.

Experimental three-bladed propeller driven by 3 h.p. electric motor—mounted for wind tunnel experiments.

The Lift Produced by an Air Propeller.

In connection with the propulsion of orthodox aircraft, the thrust produced by the propeller has been already very fully investigated. In the case of the helicopter, the lift corresponds to the orthodox thrust and the amount to be expected from a rotor of a given size can therefore be already predicted. A lifting screw with three trapeze-shaped blades was accordingly designed and tested over a wide range of operative conditions in the wind tunnel. Fig. 1 shows the model screw, which is driven by a 3 h.p. electric motor. The screw is mounted on the wind tunnel balance and all the forces and moments were measured with the screw acting either as a helicopter or Cierva Autogiro. The measurements have to be carried out with great care, since the arrangement is subjected to many sources of error, too numerous to mention in detail in this paper. There is, however, one source of error to which I will refer, since it also affects the functioning of the full scale helicopter. This is the so-called ground effect. When the lifting screw approaches a large horizontal surface (the distance being of the order of the diameter of the screw) both the thrust and torque absorbed

increase materially. This so-called ground interference very markedly affects the performance of the full scale helicopter. Thus if the apparatus takes off from the ground at a certain throttle opening, it will only rise a few metres and hover at this height unless the throttle is opened further. If the power reserve is thus insufficient, it may be impossible to get the helicopter above this so-called " floating " altitude. On the other hand this " bolster " effect when approaching the ground is most welcome when the helicopter is landing. In the laboratory, however, the ground effect is very troublesome since it is generally difficult to mount the experimental model at a sufficient distance from fixed obstacles. Up to the present only few experiments on this subject have been carried out, the best of these having been made by Flachsbart in 1928. Our own researches are in good agreement with these as is apparent from Fig. 2, which shows Flachsbart's results

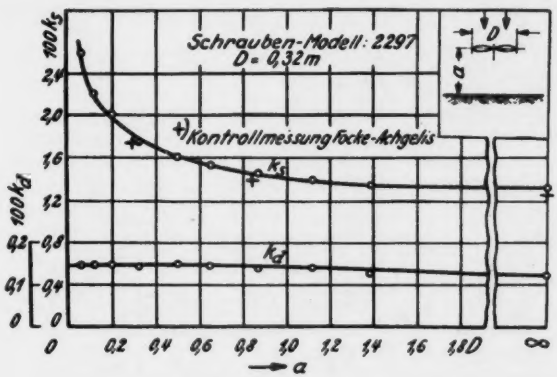


FIG. 2.

Experiment by Flachsbart on the ground effect on an airscrew.
Schraubenmodell 2297 = model screw No. 2297.
Kontrollmessung Focke—Achgelis = control measurement by Focke—Achgelis.

together with our own, the latter being indicated by crosses. The upper curve shows the increase in thrust, whilst the lower gives the increase in torque, the distance from the ground being expressed in terms of the diameter of the propeller.

CONTROL AND STABILITY.

No system of control is thinkable without previous existence of a complete balance of the couples. Now the helicopter presents a well-known difficulty which has impressed itself on all the attempted solutions carried out to date. The slowly rotating rotor exerts a powerful reaction torque on the body of the helicopter, this torque being of the order of hundreds to thousands of kg.m. The designer must deal with this reaction and the method employed by him will fundamentally affect the design of his complete machine. Many solutions of this problem have been proposed and most of these are illustrated diagrammatically in Fig. 3.

(*a*) Two propellers mounted vertically above one another and rotating in opposite directions (Breguet, d'Askanio, Pescara, Asboth).

(*b*) Two propellers mounted behind each other (Cornu) or 4 propellers mounted at the corners of a square (de Bothezat, Oehmichen).

(*c*) Two propellers mounted side by side and rotating in opposite direction (Berliner, Focke).

(*d*) Two propellers mounted behind each other, rotating in the same direction, their axes being inclined so that the resultant lateral components balance the reaction torque (Florine, Belgian Government).

(*e*) A single large propeller, driven by subsidiary thrust propellers mounted on the blades (Isacco, Curtiss-Blecker).

(*f*) A single large propeller, the blades of which oscillate in a vertical plane so that no reaction torque is produced.

(*g*) A single large propeller, the reaction torque being balanced by the thrust of one or more subsidiary propellers suitably mounted at some distance from the fuselage. (V. Baumhauer, Dutch Air Ministry).

(*h*) A single large propeller, the reaction torque being balanced by placing suitable control surfaces in the slipstream of a single subsidiary propeller discharging towards the rear. (Hirtenberg Munition Factory, Austria).

(*i*) Control surfaces placed in the slipstream of the main lifting propeller (Hafner and Nagler, Austria).

(*k*) A reaction nozzle drive for the blades of the lifting rotor (Dornier patents, Papin and Rouilly, France). A variation of the above is the proposal to use a single blade lifting screw (fitted with a balance weight) and driven by compressed air reaction.

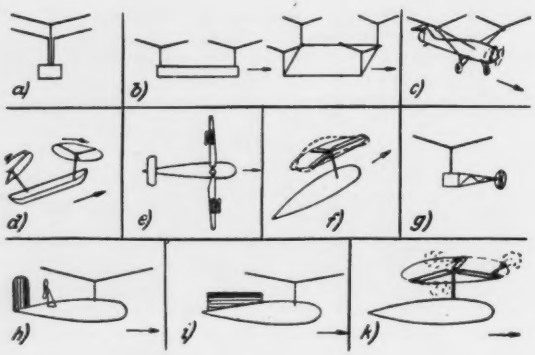


FIG. 3.

Proposals for absorbing reaction torque.

From the above proposals, we can at once rule out all those which entail either additional power or loss in efficiency. Thus proposal (*e*) suffers from the low efficiency under which the small subsidiary propellers work and this entails a loss of the order of 30 per cent. of the energy available for the main rotor. A similar objection applies to proposals (*g*) and (*h*), since the production of the reaction force will again entail a continuous consumption of energy of the order of 20-30 per cent. of the power required by the lifting screw. In addition we must rule out for the present all proposals resting on insufficient theoretical or experimental basis. This applies to (*f*) and (*i*). It is, however, quite possible that the reaction or oscillatory wing drive may be taken up later when the helicopter problem has been advanced sufficiently by practical experience. The proposal (*d*) offers no advantages over (*b*) and (*c*), the inventor wishing to retain the gyroscopic couple which is lost if the propellers rotate in opposite directions. If finally for mechanical reasons, we rule out all proposals necessitating more than two lifting screws, we are left with three possible solutions:

(1) Two rotors rotating in opposite directions, placed above each other.
(2) Two rotors rotating in opposite directions, placed behind each other.
(3) Two rotors rotating in opposite directions, placed side by side.

So far, solution (1) has been most favoured by experimenters. The French helicopter Breguet-Dorand, which was the most successful machine prior to our own, belonged to this class. If, however, we examine carefully why so many designs of this type proved unsatisfactory, we are forced to doubt whether this solution is to be recommended. Designers experimenting with this type have constantly complained of almost insurmountable difficulties associated with vibrations induced in the structure by the two propellers rotating above each other. In addition, the overall efficiency of two propellers mounted in this way is generally smaller than the individual efficiency of each propeller working on its own. The slipstream of the combination is necessarily directed over the total surface of the machine (fuselage, control surfaces, etc.), which causes a further reduction in thrust. Quite a simple calculation shows that the losses arising from this, practically make up for any structural gain in weight which this arrangement may possess over a side by side arrangement of the lifting screws. A further drawback with this arrangement is the fact that only a smaller surface is available for emergency landings under autogiro conditions.

If the two lifting screws are arranged one behind the other, there also exists a very considerable interference between the front and rear screws when the helicopter is undergoing a forward motion. We must always remember that the downwash behind a lifting screw is very much in excess of anything occurring in orthodox aircraft and with the two rotors behind each other, a distribution of longitudinal moment is likely to arise which it would be impossible to cope with under actual flying conditions. These considerations reduce the three possible arrangements to one only, *i.e.*, arrangement of the lifting screws on either side of the fuselage. In this case there is no detrimental interference between the two screws and no forced vibrations are set up. The full disk area of both rotors is available for emergency landings under condition of autorotation and the mutual induction existing between the two rotors acts in the sense of an increased aspect ratio. The efficiency of the combination is equal to the individual efficiencies of the rotors. The slipstream of either is clear of the main fuselage of the helicopter and will only meet the absolutely essential member of the frame supports. The space occupied by the side by side arrangement is also not very different from that of the vertical double rotor, for whilst the span of the latter may be a little less, this is made up in increased length, and especially height, of the complete helicopter fitted with vertical screws placed above each other.

We have now arrived at last, at the point where we can pay some attention to the question of stability and control. In many previous attempts, the helicopter was controlled and stabilised by means of control surfaces resembling those in use on orthodox aircraft. If, however, the helicopter is hovering, such a method of control is not directly applicable. It might be considered possible to obtain the necessary results by placing fins or rudders in the slipstream of the lifting rotors or in that of a subsidiary propeller. Both these methods had already been tried by others with little success and our own early attempts in that direction did not prove any more satisfactory.

It is obvious that a method of control and stabilisation by a direct change of the rotor blade incidence is more in line with the fundamental principle of the helicopter, and this line of development was consequently adopted in our own machine. Both stability and control were especially considered for the brief period when changing over from helicopter to " Autogiro " conditions. We were able to give the pilot detailed instructions as to the control movement which might be necessary, including inclination of fin. As a matter of fact, the change-over took place exactly as predicted by us, and the very first trial resulted in a perfect three point landing from an altitude of 400 m. Within two seconds of changing over,

the apparatus had already taken up a normal gliding attitude. It may truly be said that the era of practical helicopters set in when pilot Rohlfs carried out this manœuvre for the first time on May 10, 1937. It has since been repeated many times and the spectre of engine or gear failure has thus been definitely laid.

I must not withhold the fact that the successful solution of this problem took a very considerable time, both in experiment and theoretical calculations. The stability calculations especially assumed awe-inspiring dimensions. Since the whole of this investigation covered new ground, conscientious work required the avoidance of approximations. Whenever the limits of mathematical possibilities entailed the neglect of certain terms, this had to be justified by lengthy experimental investigations. The final success, however, justified all the trouble taken. The first free flight of my apparatus lasted 28 seconds, the fourth 16 minutes. Whilst the major part of this increase can without doubt be attributed to the skill of the pilot Rohlfs, such rapid progress is unthinkable unless the technical problems have been thoroughly mastered. Even under these conditions the development of an entirely novel type is necessarily a dangerous matter.

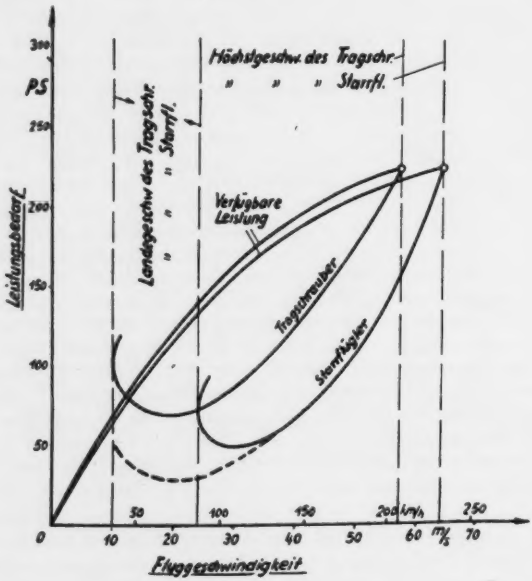


FIG. 4.

Comparative power requirements of rotary and fixed wing aircraft.
Leistungsbedarf = power required (h.p.).
Tragschrauber = Autogiro aircraft.
Starrflugler = fixed wing aircraft.
Hochstgeschwindigkeit = max. speed.
Fluggeschwindigkeit = flying speed.
Verfugbare Leistung = available h.p.
Landegeschwindigkeit = landing speed.

PERFORMANCE.

From the point of view of performance, I would like to differentiate between what has already been achieved or may be realised in the immediate future and what may be expected when rotary wing aircraft have become fully developed.

(*a*) CIERVA AUTOGIRO.

Schrenk has carried out an interesting comparison between the Cierva Autogiro and the fixed wing aircraft. The corresponding characteristics are given in Fig. 4. The difference in performance shown is, however, partly due to the greater body drag of the rotary wing machine. It may be expected that this drag can be reduced in future by improved aerodynamic design in so far as it concerns the rotor hub and starting gear. Making due allowance for this, it appears that the Cierva Autogiro of the future will still only reach 90 per cent. of the horizontal speed of the corresponding fixed wing aircraft. As a return for this, it will, however, possess approximately half the minimum speed. From the point of view of rate of climb, the comparison is, however, much less favourable for the Cierva Autogiro. Since the latter is working on a higher portion of the polar curve, the resistance becomes very great. The minimum power required for keeping aloft is considerably greater than that of the corresponding fixed wing machine and this minimum power corresponds to a lower translational speed, which in its turn affects the nose propeller efficiency deleteriously. This fact confirms our original opinion, that the Cierva Autogiro will never have a future as such, but must be considered as a half-way house to the helicopter. In this connection it does not quite solve half the problem, since, although it can land in a restricted space, it cannot hover, and the take-off and climb are worse than that of orthodox aircraft. As far as structural weight is concerned, it does not look as if the

	Steiggeschwindigkeit am Boden m/s	Fluggewicht kg
Fw 44 Stieglitz Drachenflugzeug	3,5	870
Cierva C 30 Tragschrauber	1,5	815
Fw 61 Hubschrauber als Tragschrauber	1,3	950
Fw 61 Hubschrauber als Hubschrauber	3,6	950

FIG. 5.

Comparison between fixed wing aircraft, "Autogiro" and helicopter.

Cierva Autogiro should be inferior to the fixed wing type. Especially in the case of large aircraft, it may well be that the rotary wing as such (due to the fact that it is under the action of centrifugal force and has not to take any pressure forces) may come out considerably lighter than the equivalent fixed wing and this saving in weight will more than make up for the weight of the driving hub and starting gear. This valuable property will also be shared by the helicopter.

(*b*) HELICOPTER.

In the case of the helicopter, the weight question is not quite so favourable, since the gear in this case has to transmit the full engine power with a reasonable factor of safety. It is obvious that the handicap will be most pronounced in the case of small machines. Thus Breguet has investigated a helicopter flying boat of 16 tons and concludes that for this size, the weight comes out less than the corresponding fixed wing aircraft whilst its translational speed is greater. Whilst

this estimate may be optimistic, there is no doubt that in the case of large sizes the inherent saving in weight of the rotary wing compared with the fixed wing will go far to compensate the extra weight of the driving gear.

As regards the maximum translatory speed, the question arises at once, whether it is better to operate the rotary wing machine as a helicopter or as an "Autogiro," *i.e.*, use a subsidiary propeller for horizontal flying. Pure helicopter action would then be restricted for starting, landing and hovering, whilst for maximum translatory speed the aircraft would work on the Cierva Autogiro or some intermediate

FIG. 6.

Free flying model helicopter built by Focke. The machine is driven by a petrol engine of .7 h.p. An altitude of 18 m. was reached.

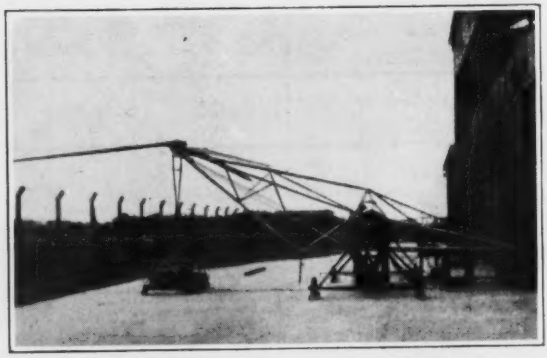


FIG. 7.

Bench test of helicopter gear (electric drive).

principle. We have investigated this problem very fully, both theoretically and experimentally and have reached the interesting conclusion that a given rotary wing aircraft will reach a considerably greater horizontal speed when flown as a helicopter, even after allowing for the 10 per cent. loss in power associated with engine cooling. Full scale flights with my helicopter have confirmed this prediction fully. Another outstanding feature of my helicopter is also its high rate of climb. In Fig. 5 are given the relative rates of climb of the FW.44 Stieglitz

(fixed wing), the Cierva C.30 Autogiro and of my machine flown either as an Autogiro aircraft or as a helicopter. In all cases the same engine (Sh.14*a*) was fitted. The weights of the different aircraft are also given in the table. Although the helicopter is the heaviest machine, its rate of climb exceeds that of the Stieglitz which is 80 kg. lighter. Flown as an Autogiro aircraft, the rate of climb is reduced to one-third. This figure is only slightly inferior to that of the Cierva machine weighing 135 kg. less. The outstanding advantage of the helicopter for rapid climb is thus obvious. In this connection I wish, however, to point out that the helicopter does not justify its existence merely by possessing equal or superior climbing power or maximum speed compared with a fixed wing machine. Its special qualities (vertical ascent and descent and hovering) put it into a class apart, and open up to it special fields of application. It is, however, a good omen for the future development of this type that its other flying qualities are of the same order as those possessed by orthodox aircraft.

Up to now I have discussed the considerations which have guided me in our development. I cannot sufficiently emphasise the scientific basis of our work, which made possible the incorporation of new results as they became available.

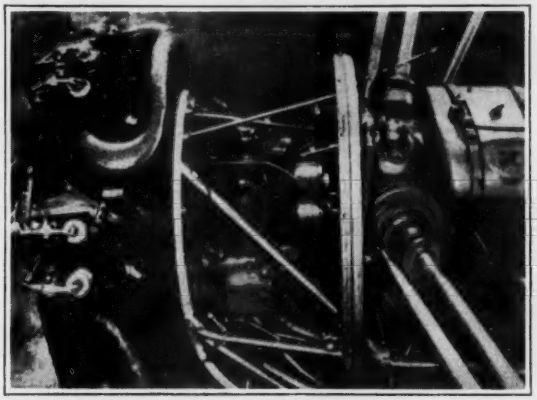


FIG. 8.

Spur gears and friction clutch.

The second and more difficult part of our work consisted in making use of this knowledge on the drawing table and in the workshop, in other words construct a practical helicopter. The first step towards this was a free flying model driven by a petrol (two-stroke) engine of .7 b.h.p. This machine weighed 4.9 kg., including 50 gm. of petrol. True this model was more often damaged than whole, nevertheless we learned much from its behaviour. In Nov., 1934, it reached a height of 18 m., which happened to be the world record for a man-carrying helicopter at this period. In addition to the model work, we also subjected the proposed drive (including blade incidence control) to a full scale test somewhat similar to the type tests to which new aero-engines are subjected. The Brandenburg Motor works, under the personal supervision of Dir. Wolff, undertook the difficult construction of the driving gear and made the necessary modification to the standard Sh. 14*a* engine. The work was carried out with exemplary care and was brilliantly successful. For the test, a single rotor and driving gear in its supporting frame was attached to a mock up fuselage and driven electrically, the Leonhard circuit adopted making accurate power measurements possible (Fig. 7). The thrust (lift) was measured by balancing the fuselage (applying the

corresponding weights), making due allowance for the ground effect. In this way valuable comparisons with model experiments previously carried out in the wind tunnel could be effected. A 50-hour continuous run of the unit was followed by a further 10 hours test after the gears had been inspected. During this last period, the blade control angle was altered continuously. Fig. 8 shows the spur gears,

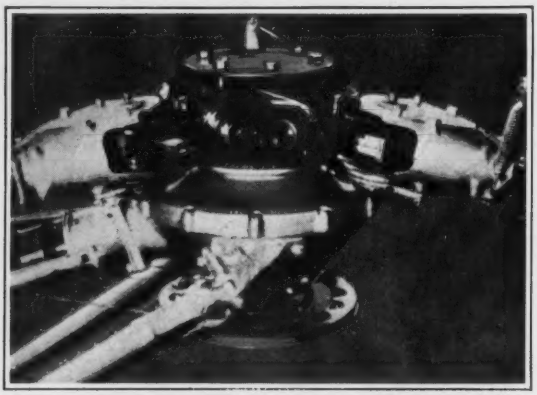


FIG. 9.
Rotor hub showing control mechanism for blade incidence control.

FIG. 10.
View of helicopter showing engine cooling fan.

the friction clutch and the safety devices which operate automatically in the case of engine or gear defects or if the rotary speed falls below a certain minimum. In all these cases, the rotors are automatically disconnected from the drive and assume autorotation automatically. Fig. 9 shows a rotor hub with the blade control mechanism. The design of the fuselage and the rotors was in conformity

with aircraft strength specifications, the object being to obtain an airworthiness certificate for the first experimental machine. For the same reason, the gears were subjected to corresponding tests at the works before installation. A special cooling propeller (no thrust) was designed and developed in conjunction with the Brandenburg motor firm, the work entailing engine cylinder temperature measurement under a variety of conditions (Fig. 10). The first experimental helicopter was flown a number of times whilst still tied to the ground (Fig. 11). Such " captive " experiments are very useful, since everything is happening under prac-

FIG. 11.
Experimental machine undergoing test whilst tethered to the ground.

FIG. 12.
The first free flight by pilot engineer Rohlfs, 26th June, 1936.

tical full scale conditions with the aircraft only 50 cm. to 1 m. from the ground. In the further full scale experiments, no single step was undertaken before the preliminaries had not been investigated either theoretically or by means of subsidiary experiments. The first free flight was carried out by engineer pilot Rohlfs on 26th June, 1936 (Fig. 12). A year later (25th and 26th June, 1937), the same

pilot was able to capture all the world's helicopter records for Germany, in several categories multiplying previous performances 15 times! The altitude reached (2439 m.) did not represent the ceiling by any means. Nevertheless it caused Mr. Asboth in a foreign scientific periodical to issue a thinly disguised accusation of fraud! Asboth was especially sceptical as to the altitude having been reached in a pure helicopter flight and presumed that the machine was really flown as a Cierva Autogiro at altitude. He claims to have proved this mathematically. Unfortunately both the dimensions and weights on which his figures are based are very far from the truth. I wish to state here categorically (and innumerable witnesses will confirm), that all my records were pure helicopter flights from start to finish. In order to remove any shadow of doubt about this, every landing in connection with these records was also carried out vertically as a pure helicopter. The pilot was specially asked to do this by the official representatives of the F.A.I. The fact that these representatives were satisfied should be sufficient, since Asboth can scarcely intend to accuse them of being bribed!

It is, however, quite correct that apart from these record flights, my helicopter has repeatedly landed with the engine disconnected, *i.e.*, under conditions of autorotation. This essential safety factor in case of engine failure had never before been demonstrated by any helicopter, including the Asboth design. An altitude of 2439 m. for my helicopter is perfectly feasible and can be demonstrated theoretically provided the investigator has command of data, which, judging from Asboth's calculations, the latter did not possess. I quite agree with Asboth, however, that there is nothing marvellous in the performances.

They represent, however, the result of 5 years of unremittant work on helicopter problems. That Asboth should be ignorant of this work of mine, as he repeatedly states in his article, cannot be helped. I also wish to state most emphatically that the construction of the helicopter is entirely my own work and based on the results of theoretical calculations, model and full scale experiments carried out over many years. If Asboth claims as he does in his article that efficient lifting screws apart from those designed by him are unknown, he seems to forget that, with patience and hard work, any and every technical problem can be mastered, provided the results aimed at are compatible with the laws of nature.

In June, 1937, the German Government took delivery of the first helicopter and this was followed by a second in October. The latter machine was flown by Miss Hanna Reitsch, in October, 1937, from Bremen to Berlin for demonstration. In this connection she was successful in establishing a new world's speed record for helicopters (108.974 km./h) over the distance Stendal-Tempelhof.

Nobody, myself included, would have thought such a performance possible, considering this is a first model and has a relatively small power reserve. This success, however, illustrates in a brilliant manner the great future possibilities of helicopter flight.

LARGE AEROPLANES.

By H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S.

(*Lecture read before the Weybridge Branch on December 1st, 1937, and before the Students' Section on March 29th, 1938.*)

§1. Introduction.

I want this evening to present some reasons for believing that we can build successful aeroplanes of enormous size, and, what is more important, that they will not be merely monuments to a desire for the gigantic.

In the past, bold computers have defined upper limits to the size of aeroplanes. Their prophecies have varied, and most of them have been belied by practical achievement. Their arguments were usually based on what has been called the "Cube Law" or the "Square-Cube Rule." This rule, though it has apparently proved misleading, is indeed correct when properly applied, and it forms a convenient point from which to begin an enquiry into the feasibility of the giant aeroplane.

In what follows, the arguments are illustrated by numerical examples. The numbers are essentially illustrative. From the quantitative point of view they can only be very rough. Reasons could easily be found for increasing them or decreasing them, but the main arguments would not thereby be affected.

§2. The Square Cube Rule.

The square cube rule is developed in this way. We take as a basis a typical aeroplane. Suppose now that all the linear dimensions, external and internal, of this aeroplane are multiplied by n. Then the all-up weight of the aeroplane, which must be proportional to the supporting wing area, is multiplied by n^2; but the essential structure of the aeroplane, the weight of which is proportional to its volume, becomes n^3 times as heavy. It follows that the *structure weight considered as a percentage of the all-up weight, is proportional to n; in other words, is proportional to the linear dimensions or the square root of the all-up weight.* This is the rule. The assumptions tacitly made in deducing it are that all aeroplanes have the same

Wing loading,*
Design factors,*
Type of structure,
External form,
Disposition of masses.

With so many restrictive assumptions the rule is clearly capable only of strictly limited application. It is, nevertheless, of interest to express it symbolically and to deduce the corresponding law of carrying capacity.

If W = all-up weight,
W_u = useful load,
W_e = engine weight, including airscrews,
$W_{ue} = W_u + W_e$,
W_s = structure weight,
k = a constant,

* It will be seen that bending moments are proportional to n^3 for constant wing loading and design factors. Moduli of sections are proportional to n^3. So corresponding bending stresses are constant as n varies. Also, shear, tensile and compressive loads vary as n^2, while the resisting areas vary as n^2. So *corresponding stresses of all kinds are constant as n varies.* Had any other result been obtained, the asterisked assumptions would have been incompatible with structure weight varying as n^3.

the rule states that

$$W_s/W = kW^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

or

$$W_s = kW^{3/2}.$$

The corresponding rule for non-structural weight is then

$$W_{ue} = W - W_s = W - kW^{3/2}.$$

This variation is represented by the curve in Fig. 1.

W_{ue} is a maximum when $\partial W_{ue}/\partial W$ is zero. That is, when

$$1 - (3/2)\, kW^{\frac{1}{2}} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

So the maximum useful load, including the engines, occurs when

$$W^{\frac{1}{2}} = 2/3\, k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This, on the assumptions stated, gives the weight of the largest aeroplane worth building. Its structure weight percentage, from (1) and (3) is

$$W_s/W = k\,(2/3\, k) - 66\tfrac{2}{3}\% \quad . \quad . \quad . \quad . \quad (4)$$

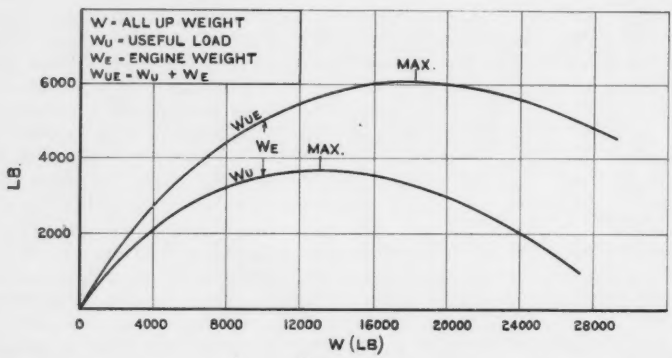


FIG. 1.

Variation of non-structural weight with all-up weight according to square cube rule.

If we wish to deduce the condition for maximum useful load, exclusive of engine weight, a further assumption is necessary. Suppose we say that engine weight is a constant proportion of all-up weight, which, as horse-power varies with engine weight, is an assumption of constant speed. Then we introduce another constant, m, defined by

$$W_e = mW$$

and instead of (3) and (4) we have

$$W^{\frac{1}{2}} = (2/3\, k)\,(1 - m) \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

$$W_s/W = 66\tfrac{2}{3}\,(1 - m)\% \quad . \quad . \quad . \quad . \quad (4a)$$

§3. CONSIDERATION OF THE CONVENTIONAL LAYOUT.

As an example, let us take as a basis an aeroplane weighing 5,000lb. with an engine weighing 750lb. and a structure weight percentage of 35. This gives

$$k = 0.35/\sqrt{(5{,}000)},\quad m = 0.15.$$

From (3), all-up weight for maximum useful load, including engines, is

$$(2/3\, k)^2 = (4/9)\,(5{,}000/0.1225) = 18{,}200\text{lb.},$$

and from (3a) the all-up weight corresponding to maximum nett useful load is

$$\{\,(2/3\, k)\,(1 - m)\,\}^2 = 18{,}200\,(0.85)^2 = 13{,}100\text{lb.}$$

Fig. 1 corresponds with these figures.

Now let us see how the situation changes if we remove some of the restrictions which have led to these superficially misleading results.

Under the heading " Type of Structure " we can immediately observe that the structural scheme which is efficient in a small aeroplane may be uneconomical in a larger one. Moreover, in a small aeroplane, it is not always possible to make all the elements of the structure as small as design calculations indicate they can be. To take but one example, the theoretical thickness for a piece of sheet metal wing covering for a small aeroplane might be so small that, if it were produced, it would be liable to serious damage or distortion from mere man-handling. Frequently in the small aeroplane heavier material than strength or stiffness requirements demand is used for this reason or for the equally powerful one that for most materials there is a minimum thickness defined by the processes of manufacture.

The large aeroplane suffers less from the effects of these limitations than the small aeroplane, so that we may expect the former to have the more efficient structure. This is the first effect tending to defeat the square cube rule.

Again, the system of factors specified for design favours the large aeroplane. We may reasonably suppose that the small, fairly fast aeroplane in the example above had a C.P. forward factor of 10. If we assume that this is a fair index figure for *all* the design factors, and if 5 is an equally representative figure for the large non-aerobatic aeroplane, then our calculations are modified in this way.

$$k = (0.35 \times 5/10)/5{,}000, \quad m = 0.15$$
$$(2/3\ k)^2 = (4/9)\ (5{,}000/0.1225)\ (10/5)^2 = 18{,}200 \times 4 = 72{,}800\text{lb.}$$
$$\{\ (2/3\ k)\ (1 - m)\ \}^2 = 13{,}100 \times 4 = 52{,}400\text{lb.}$$

A further gain on the smaller figure follows if we allow the large aeroplane to be slower than the small aeroplane. If the power loading is reduced so that $m = 0.1$, the economic weight changes from 52,400lb. to $52{,}400\ (0.9/0.85)^2 = 58{,}400$lb. I do not propose to retain this particular gain in what follows. I feel that the large aeroplane ought to be as fast as the small one.

Another factor which has upset early estimates of the size of the largest aeroplane is the steady increase in wing loading, assumed constant in the square cube law. Now stalling speed is proportional to the square root of wing loading divided by maximum lift coefficient, so it follows that if landing speed is to remain constant, increase in wing loading must be accompanied by increase in maximum lift coefficient. This has been accomplished by the introduction of flaps and slots.

We can imagine the aeroplanes in the examples I have given to belong to the middle 1920's, when a wing loading of 12lb./ft.^{2} was reasonable. To-day we are used to 24lb./ft.^{2}. This means that our basic aeroplane would now weigh 10,000lb. instead of 5,000lb. The wing bending moments would be doubled, and, arguing approximately, we can deduce that this would mean that the weight of the wing structure would be doubled. The fuselage structure weight might be expected to increase in about the same ratio, leaving the structure weight percentage still about 35. This doubling carries through the calculations for the " largest aeroplane " and leads us to

$$2 \times 72{,}800 = 145{,}600\text{lb.}$$
$$2 \times 52{,}400 = 104{,}800\text{lb.}$$

There are British flying boats in the design stage with wing loadings in the region of 40lb./ft.^{2} already, and the Savoia Marchetti flies regularly with a wing loading well in excess of this, so the day is clearly not far distant when loadings of about 50lb./ft.^{2} are common. Let us then conclude this stage of the argument with the impressive figures:—

$$4 \times 72{,}800 = 291{,}200\text{lb.}$$
$$4 \times 52{,}400 = 209{,}600\text{lb.}$$

So far we have not particularised the shape of our aeroplane, but we have presumably had in our minds the sort of layout with which we are familiar to-day.

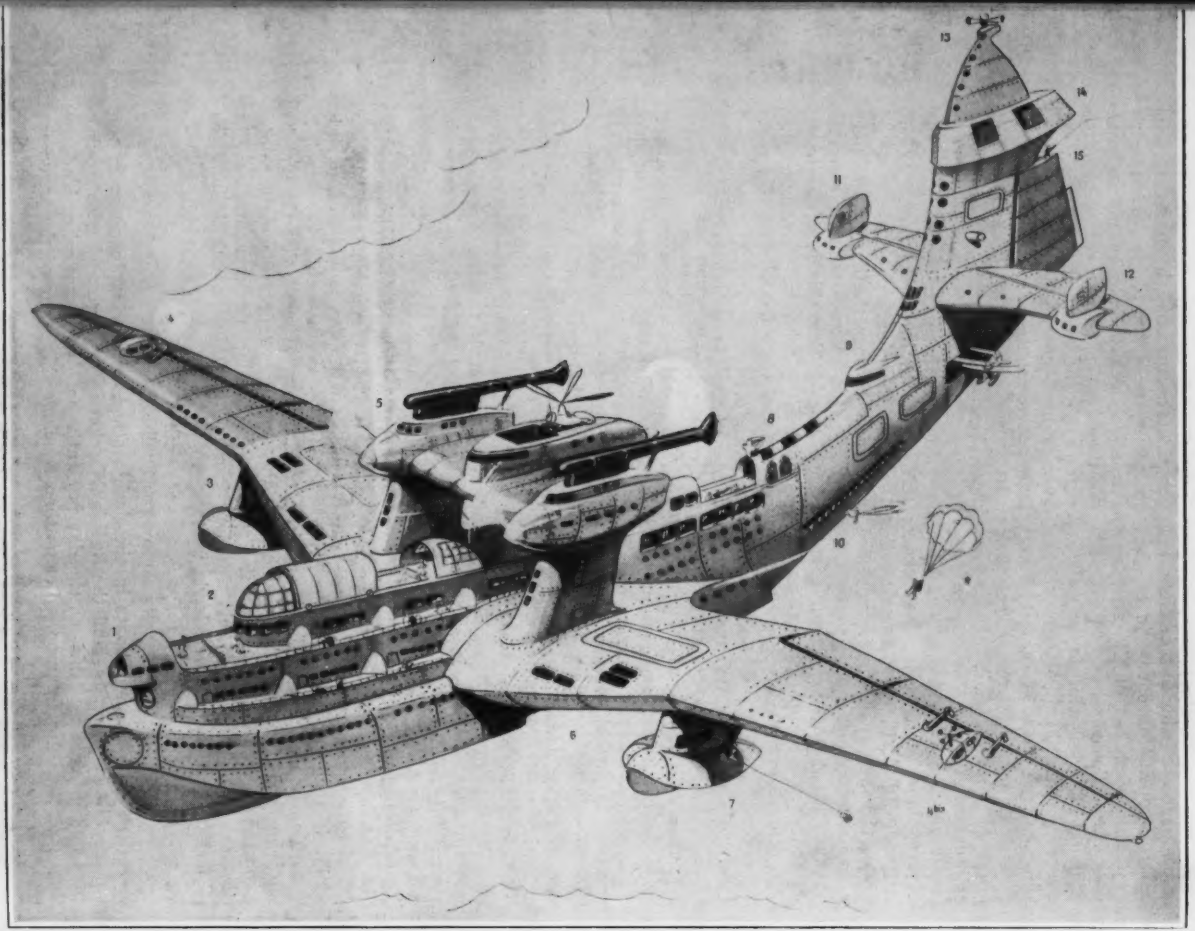


FIG. 2. *Courtesy of the artist Lucien Cave and Editor of "L'Aeronautique."*

1, poste de pilotage; 2, salle à manger des premières classes; 3, pavillon de bridge; 4 et 4 bis, nurseries (vue sur les guignols, chevaux de bois actionnés par moulinets anémométriques); 5, rampe d'échappement symphonique à tonalité réglable; 6, perception; 7, cuisines; 8, chapelle; 9, institut médico-légal; 10, échappement libre (parachutes-sièges); 11 et 12, locaux disciplinaires; 13, serre-freins; 14, studios pour artistes; 15, pêche à la cuiller au poisson volant.

The arguments have marched with the square cube rule in assuming that, while size has increased, the general disposition of areas and masses has remained constant. In other words, with the conventional aeroplane of to-day obsessing our minds, we have probably visualised the giant we hope to achieve like that of Fig. 2.

Much as I admire this magnificent conception, I think that it is misleading. It is much too like aeroplanes as we know them, and, though my actual numbers may be proved inexact, there seems little doubt that they indicate a real economic limit to the size of aeroplanes if we retain the conventional distribution of areas and masses. In fact, the departure from this arrangement has already begun, another departure, that is, from the assumptions leading to the square cube rule. It is happening like this.

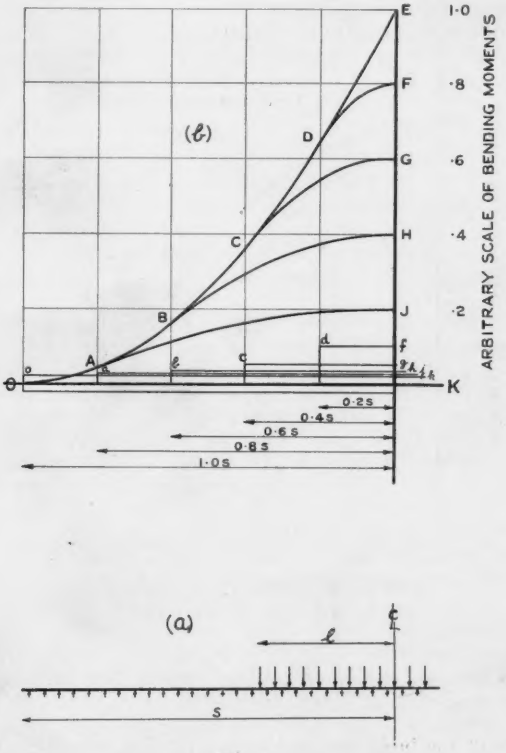


FIG. 3.

Effect on bending moment of spreading the load on a uniformly supported beam.

§4. EFFECTS OF CHANGES IN LAYOUT.

With the attainment of craft of the sizes we have just been discussing, the space in the wings begins to be available for stowage. Thus, we can if we wish put some of the useful load in the wings and correspondingly less in the fuselage. This leads to a reduction in structure weight on two counts. First of all, in so far as the accommodation of load has dictated fuselage bulk, the

size of the fuselage, and in consequence its weight, can probably be diminished. Secondly, any tendency to spread load over the span reduces wing structure weight. This second effect is of such importance as to warrant illustration.

At least 60 per cent. of the wing structure weight is that of the main spars, whose weight is dictated by the requirements of flexural strength. Any considerable reduction in flexural bending moments, resulting as it must in material savings in spar structural weight must, therefore, effect a useful saving in wing structure weight. Spreading the load spanwisely provides this reduction, as can be seen from a simple example.

Consider a light beam, of length $2s$, shown in Fig. 3*a*. This beam may be taken as analogous with the spar structure of a monoplane. It is loaded vertically upwards with a uniformly distributed w_s per unit length. This may be taken to represent aerodynamic lift forces less the weight of the beam itself. It is loaded downwards with a uniformly distributed load w_1 applied symmetrically

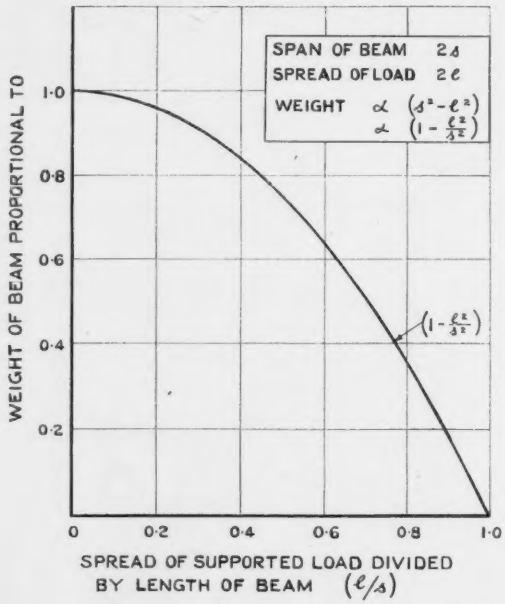


FIG. 4.

Effect on weight of uniformly supported beam of spreading load.

about the middle of the beam over a length $2l$. This may be taken to represent the weight of the rest of the aeroplane. Necessarily

$$w_s s = w_1 l.$$

Now the case of all the useful load in a narrow fuselage can be represented by taking l very small. Sufficiently approximate for our present argument is to take for this case $l=0$, that is, to suppose the other-than-wing-weight to be concentrated downwards at the middle of the beam. The bending moment diagram, to which the beam's weight may be taken as roughly proportional, is then OEK in Fig. 3*b*. If we spread the w_1 load so that l is $0.2\,s$, the bending moment diagram becomes $ODFK$. When $l=0.4\,s$, it is $OCGK$. When $l=0.8\,s$, it is $OAJK$; and of course when $l=s$, it is everywhere zero $-OK$.

From this we see that the more the supported weight is spread over the beam, the more impressive is the saving. It can be shown quite easily, in fact, that the weight of the beam in our illustration will vary very nearly as $s^2 - l^2$, that is, as in Fig. 4. Clearly, we must take advantage of this possible saving.

Let us go back to our aeroplane of 209,600lb. Its structure weight is $66\frac{2}{3} \times 0.85$ per cent. $= 56.7$ per cent. Of this, about 28 per cent. will be wing structure; the rest fuselage and tail structure. Of this 28 per cent., 60 per cent. will be flexural structure and the rest torsional and subsidiary structure. In other words, 17 per cent. of the all-up weight is flexural structure, and 11 per cent. the rest of the wing. Now suppose the useful load is spread across 0.6 of the span. There may not be enough head room for the passengers, but don't let's quibble. If we do this, there will be nothing for the fuselage to carry except the tail. As this seems wasteful, let us liquidate the fuselage and continue as a Pterodactyl. From Fig. 4, the wing flexural structure will be about 0.6×17 per cent. $= 10.2$ per cent.; as we have not modified the torsional structure the total structure weight, all wing structure weight, is approximately 21 per cent.

Now the square cube rule can be applied to this new distribution of areas and masses. As

$$k = 0.21/\sqrt{(209{,}600)}, \quad m = 0.15,$$

our largest aeroplane is now from (3)

$$(4/9)\ (209{,}600/0.0441)\ (0.85)^2 = 1{,}580{,}000\text{lb.} = 680 \text{ tons}.$$

There will be plenty of head room in this. In fact, so much, that we probably regret that we did not spread the load over the whole span and have a few more tennis courts. We have, however, already reached a stage which assumes the defeat of difficulties which we have not even formulated. In other words, we have probably gone too far. We may, however, examine our position from other angles.

Suppose we *had* spread the load over the whole span, spread it so that every element of mass was balanced by an element of lift on the same chord. Then we should need no primary flexural structure at all. And suppose we had been sufficiently cunning to arrange our axes of torsion and inertia at the quarter chord position, so that flutter and divergence are impossible whatever the stiffness of the wings. And suppose that we have discarded the clumsy aileron and devised a lateral control which does not depend on wing torsional stiffness. Then we need no primary torsional structure either. This does not really mean that our structure weight has fallen to zero. We have got to build the thing of *something*. But the something is all secondary structure, so to speak.

This sort of argument leads to extremely small structure weights and the credulous may visualise aircraft of Brobdingnagian dimensions. But the argument is fallacious on at least three counts:—

(1) With spans running to several hundred feet, the possibility of the aeroplane being only *partly* caught in an up or down gust must be taken into account. This will produce quite respectable bending moments.

(2) In flight, localisation of engine and other heavy masses, movement of passengers and uneven emptying of fuel tanks make the ideal balancing of mass and lift impossible.

(3) It does not seem possible to land or take-off in such a way as to get below every item of mass an equivalent supporting force.

Now if we did spread the load over the span, we should find that the gust loading case visualised would control flexural design. I have considered the case of the flying wing supported by a uniformly distributed lift and carrying a uniformly distributed load suddenly encountering a gust stretching from one wing tip to a point short of the other. It can be deduced that the worst bending moments occur when the gust extends over 0.23 or 0.77 of the span. The maximum bending moment is then about one-eighth the maximum for the case of the beam with the carried load concentrated in the middle. Allowing that

the load in large aeroplanes of conventional form is distributed to some extent and that the ideal spreading is unlikely of practical attainment, it would appear, nevertheless, conservative to assume that the flexural structure of our flying wing if determined by the gust case described would be one-quarter the weight of that of the wing structure of the conventional craft.

It is not possible to reach any final estimate of structure weight along lines so far removed from experience. But the general argument indicates that the estimate on which the structure weight of our 680-ton craft was based may well be conservative, even when the uneven distribution of masses mentioned under (2) above is taken into account.*

In connection with landing and take-off loads, we must hope to approximate in some way to a distributed ground or water reaction. A multitude of wheels seems to me less satisfactory than a widely distributed water plane area. The giant aeroplane would need giant aerodromes and I suggest that to use the boundless sea is the cheapest way to meet this situation, particularly as the nuisance of undercarriage retraction is then avoided. A year or two ago, Mr. Coombes and I decided to discover how a flying wing would behave on the water, and we tested the shape shown in Fig. 5. Every section was a true

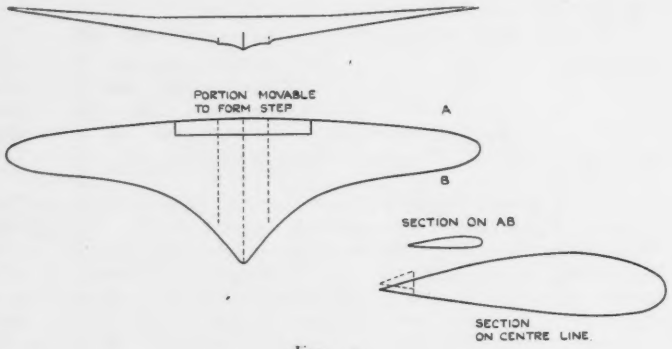


FIG. 5.

Hull-less seaplane tank model.

aerofoil section, and the chine and keel lines were obtained by sudden changes in the rate of change of aerofoil thickness. A biplane boat with this as the bottom wing, and no hull, had the take-off resistance curve shown in Fig. 6, where also is given the corresponding curve for a good conventional type of flying boat. Clearly the flying wing wins on distance to take-off, and the supporting water load spreads over the span at low speeds. We believe that this scheme is the sort the giant craft of the future will need.

Before leaving this structural argument, let us examine briefly the stock criticism of the large aircraft. "Would not two aeroplanes each of half the all-up weight carry more useful load between them?"

Consider the curve marked 10 in Fig. 7. This represents the variation of non-structural weight with all-up weight for some given geometry of lay-out,

* With regard to this, it is difficult to estimate the effect on structure weight of the inevitable localisation of load. The minimisation of effects of this kind is one of the problems of airship design wherein experience has shown how great are the savings to be obtained by careful disposition of the masses. In the airship the solution of the problem was largely spoilt by the standard requirement that the ship had to be amply strong when any one gas bag was deflated. In the aeroplane this would be paralleled by an empty fuel tank in a region where others were full. It should not be difficult, however, to arrange for an even diminution of fuel load over the span, so that the problem in the aeroplane should be easier to deal with.

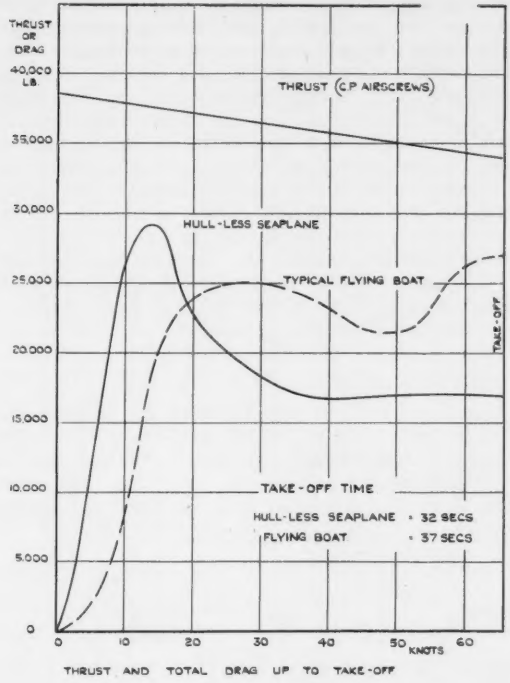


FIG. 6.

Hull-less seaplane and typical flying boat compared.

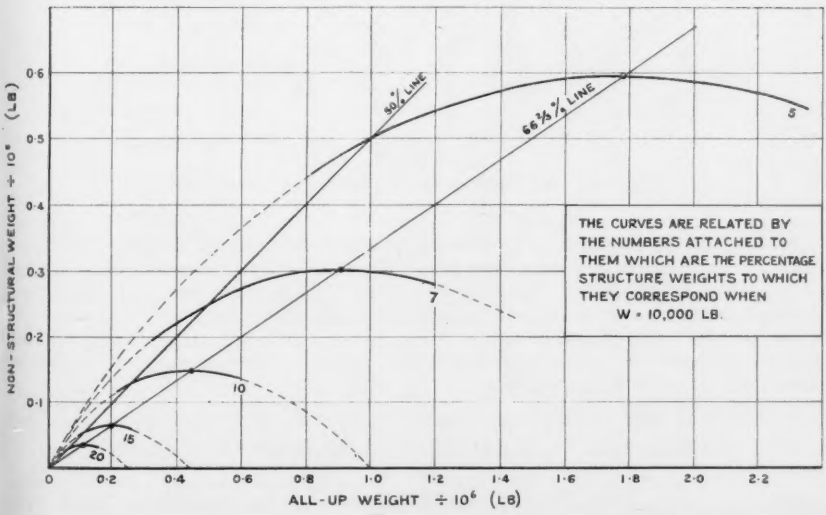


FIG. 7.

Variation of non-structural weight with all-up weight.

mass distribution and wing loading. The maximum of this curve indicates that the biggest aeroplane for the given conditions weighs 450,000lb. and would carry 148,000lb. in useful load and engines. It is quite clear that two aeroplanes built to the same conditions, each of half this weight, would carry 120,000lb. each, or 240,000lb. together. I suggest, however, that the large aeroplane and the smaller ones would *not* be built to the same conditions. For example, if we wished to build an aeroplane of 900,000lb. we should not stick to curve 10. Taking advantage of spanwise load spreading, higher wing loading, etc., we should move up to some curve such as 7, inapplicable at weights of smaller order, and achieve the *same* structure weight percentage as we did in the 450,000lb. aeroplane. In other words, my view is that as we increase in size we find more and more ways to economise in structure. If we assume that all the curves are possible curves, all the maxima represent the corresponding " largest aeroplanes." The line through *these* is then the line along which we travel. And as it is a straight line, we may infer that *the sky's the limit.*

§5. Apparent Limitations to Size.

The argument so far has been based chiefly on considerations of structure weight; it has led us to a craft of 680 tons all-up weight. Although this has been described as a " flying wing," we have not looked closely at its geometrical form. When we do so, we discover that the *attainment of such a craft depends on important advances being made in our system of propulsion.* This is the argument.

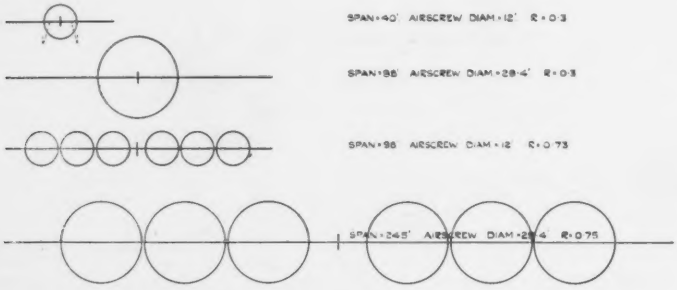


Fig. 8.

Diagrams relating to span covered by airscrews.

So long as horse-power is a constant proportion of all-up weight, then for a constant number of airscrews, the proportion of the span covered by airscrews is constant, other things being equal. This means that the total power put through one airscrew must vary directly as the all-up weight. This leads us quite soon to a size of power unit which present knowledge suggests is a limiting size or, alternatively, if we assume that two or more power units can be coupled to one airscrew, to a limiting diameter of airscrew.

To proceed further we can only assume increase in *number* of airscrews. Then

$$\{\text{Span covered by airscrews}\} \propto \text{No. of airscrews} \propto \text{h.p.} \propto W.$$

But

$$\text{Span} \propto W^{\frac{1}{4}}.$$

Therefore the ratio

$$R = \text{Span covered by airscrews/Total span} \propto W/W^{\frac{1}{4}} \propto W^{\frac{3}{4}} \propto \text{span}.$$

Let us see where this argument leads us. We have taken in the numerical examples in this lecture engine weight as 0.15 W. If we take engine plus airscrew weight as 2lb. per horse-power we have

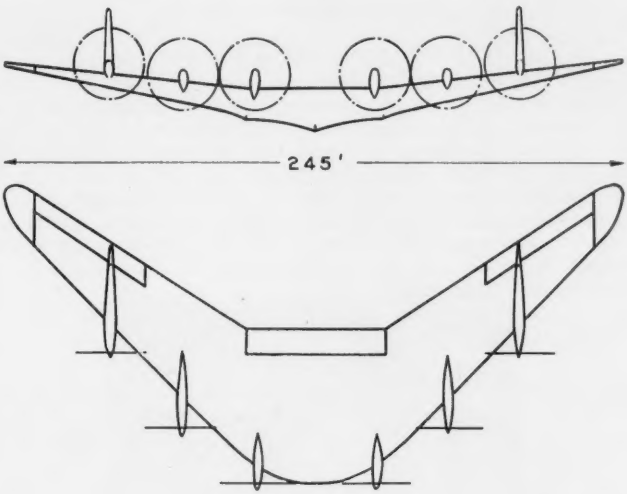
$$\text{h.p.} = 0.075\ W.$$

If we take as basis a 1,000 h.p. engine with a 12ft. diameter airscrew

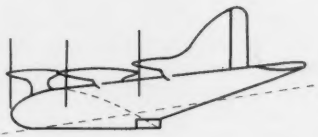
$$1{,}000 = 0.075\ W$$

so

$$W = 13{,}300\text{lb.}$$



STRUCTURE WEIGHT	200000 LB.
ENGINES & AIRSCREWS	80000 "
FUEL	145000 "
FITTINGS	15000 "
200 PASSENGERS & BAGGAGE	50000 "
20 CREW	5000 "
MAIL	5000 "
ALL UP WEIGHT	500,000 LB.



HORSE POWER	37,500
TOP SPEED AT 15000'	360 M.P.H.
CRUISING SPEED AT 15000'	315 M.P.H.
LOADING	50 LB/FT^2
RANGE IN STILL AIR AT CRUISING SPEED.	4000 M.

FIG. 9.

Working on our high wing loading of 50lb./ft.^{2} and an aspect ratio of 6, this aeroplane would have a span of 40ft. (see Fig. 8). So

$$R = n\ 40,\ \text{say},\ = 12/40 = 0.3,$$
$$i.e.,\ n = 0.3/40.$$

Suppose we believe that we can put 6,000 h.p. through one airscrew. This may mean that we believe that we can build an engine of 6,000 h.p., or that we can couple two or more engines to one airscrew and that this power gives the

biggest airscrew we care to believe in; its diameter is $12\ (6{,}000/1{,}000)^{\frac{1}{4}} = 12\sqrt{6} = 29.4$ft. If it is the only airscrew, our aeroplane weighs $6 \times 13{,}300$lb., has a span of $40\sqrt{6}$ft., and still $R = 0.3$.

Now, in proceeding to bigger craft, we take as our unit 6,000 h.p. driving a 29.4ft. airscrew. We will suppose that we reach a practical limit when three-quarters of the span is covered by a single line of airscrews. That is, the limit is reached when

$$R = 0.75 = \pi s = (0.3/40\sqrt{6})\ s.$$

This gives

$$s = (0.75/0.3)\ 40\sqrt{6} = 245\text{ft.}$$

and

$$W = (245^2 \times 50)/6 = 500{,}000\text{lb.} = 223\ \text{tons.}$$

This is rather disappointing. We expect, from the point of view of structural development, to be able to build aircraft of three times this weight. How can we pass the barrier?

There seem to be various possible methods to be used singly or in combination.

First, airscrew diameter varies theoretically as the square root of solidity. Thus, changing the number of blades from 4, which corresponds to the diameters I have been discussing, to 8, would mean replacing a 30ft. airscrew by one of the order of 22ft. diameter. The difficulties in the way of doing this are chiefly constructional. If we succeed, we see immediately by the foregoing calculations, that the limiting span becomes

$$245\sqrt{2} = 346.5\text{ft.}$$

and the limiting weight

$$223 \times 2 = 446\ \text{tons.}$$

Secondly, airscrew diameter is largely dictated by take-off considerations. For a large flying boat the length of take-off run would not matter much, so that airscrew diameter could be further reduced a little at the expense of take-off efficiency. Further reduction follows if we use some method of assisted take-off. The attractive Mayo composite scheme seems inapplicable to the huge sizes we are talking of, and the appropriate catapult would be a pretty expensive item. Fuelling in the air would need a gigantic tanker, and some means of assisted take-off contained in the aircraft itself seems the most practicable; one visualises water screws or rockets for the purpose.

Thirdly, for truly high speed aircraft, the use of the two-speed gear would give another reduction in the airscrew diameter required for take-off.

Fourthly, it may be possible to develop a tandem airscrew system applicable to modern layouts.

With these lines of development in mind to bridge the gap between the 446 tons and the 680 tons we prophesied on structural grounds should not be difficult. If we were ordered to begin work on the biggest possible craft to-morrow, however, we should perhaps be ill-advised to attempt anything bigger than the 223 tonner! This may be regarded as the order of size we may hope to attain by applying existing practice. That is, making no assumptions in drag reduction beyond that following repression of fuselage and elevators, and no appeal to assisted take-off, high solidity airscrews, or two-speed gears, we should be capable of building in the next few years something on the lines of Fig. 9.

For the 680 tonner we shall have to wait a little longer.

ANODIC OXIDATION OF ALUMINIUM AND ITS ALLOYS.

By J. Donaldson Craig.

(Lecture read before the Weybridge Branch of the Society.)

Within recent years the subject of anodic oxidation has been very fully and minutely examined, notably by Bengough, Stuart, and Dr. Sutton, who was responsible for the large-scale experiments carried out at the Royal Aircraft Establishment, Farnborough, and who, with his collaborators, has presented a number of excellent papers to the Royal Aeronautical Society, the Institute of Metals, and other bodies. In addition, scientists and industrialists at home and abroad are continuously adding to knowledge of aluminium, its uses and adaptability, and are giving a growing impetus to penetrations into spheres formerly exclusive to steel, brass, copper, tin and timber, each substitution calling for special consideration, so that it is well-nigh impossible for one to broach the subject without impinging somewhere upon the work of others.

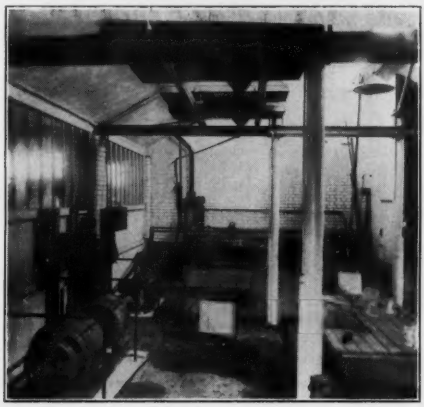


Fig. 1.

The results of laboratory investigations and large-scale experiments were first published in 1926 by the Department of Scientific and Industrial Research, and covered almost every aspect of the subject, but as this publication was a limited one, it has not been available to many who are deeply interested.

Anodic oxidation is no new thing, but has been known and understood by many for a considerable number of years. Against this, however, must be set the fact that it is only comparatively recently, coincident with the expansion in the light metal industry, chiefly the aircraft industry and the enormous increase of the personnel in the industry, that interest has widened in keeping with the importance of protective treatments of the materials employed. Furthermore, the rapid progress made in the change over to all-metal construction when parts are stamped out, machined and ground up with a precision that is monotonous in its regularity, has brought even the youngest apprentice into touch with anodic treatment, and this speed of production has demanded a like speed up in protective treatments of components.

To the lay mind aluminium stands in no need of protection, being in itself highly resistant to corrosion, due no doubt to the presence of a film of protective oxide. By a process of natural oxidation the film is renewed upon the surface if cut or scratched, but such film is, in itself, insufficient to withstand the rigours of attack from varying sources, such as atmospheric conditions, proximity to and immersion in sea water, with alternate wetting and drying, contact with the human body and other corrosive agents, the chief factor being the oxygen content of such agents, hence the increased attack experienced with intermittent as opposed to continuous immersion, and the greater degree of corrosion occurring at the water line. If, however, the natural oxide film can be replaced or built up by an artificially operated film having adherent strength and thickness, then the resistance of the metal to corrosion will be likewise greatly increased. The normal Bengough treatment has resulted in the natural film being increased approximately 100 times.

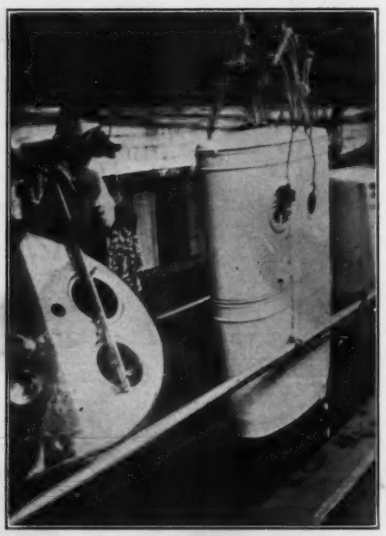


FIG. 2.

Experiments in this direction led to the adoption of an electrolyte of dilute chromic acid, a powerful oxidising agent, in which the metal to be processed was made the anode. It will be observed that whereas in the familiar process of electro-deposition, the metal to be plated is made the cathode in a bath containing a solution of a suitable salt of the metal to be deposited, in the anodic process, the metal to be processed is immersed in solution which does not contain aluminium in any form, and further, the aluminium article is made the anode, hence the term "anodic oxidation" or "anodising."

In outward appearance an anodising plant is similar to a plating plant, but whereas in plating a few volts potential at constant value is sufficient, in the anodic process an E.M.F. capable of being controlled from zero to at least 50 volts is required.

Fig. 1 shows a small unit of 250 amperes 70 volts. The foreground to the right and the rear (not shown) is occupied by benches for the preparation of the work, cleaning, swilling and drying tanks. To the left is shown the heart of the plant in the direct coupled motor generator, having variable resistances for controlling the voltage to the bath which stands in the background. At the left-hand

end of the bath are arranged extraction fan, agitator paddle and circulating pump for the cooling coil within the solution, while on the girders are supported tanks containing filtered rain water for the replenishment of the bath so that evaporation losses may be made good daily. There are three longitudinal rails over the bath, the central one being the positive rail carrying the work, while the two outer rails are on the negative side of the circuit, and carry stainless steel cathodes. The heating is by gas burners beneath the treatment tank.

The process of anodic oxidation is no exception to the rule of cleanliness first and last to ensure successful results. All grease and adhering impurities should be removed by the application of petrol, benzole or one of the proprietary brands of cleaner sold for that purpose. Washing in hot water should follow, particularly in the case of welded articles which might harbour traces of welding flux. If this is allowed to remain in cavities or folds, the combination with chromic acid will result in local pitting during treatment. In some cases this pitting may not be visible owing to the action taking place within the cavity, but may appear 24 hours later in the form of pin holes.

Thereafter, the article is transferred to the bath containing 3 per cent. pure chromic acid dissolved in water and maintained at 40 degrees C. Before using tap water tests should be made to determine sodium chloride content which should not exceed 0.020 grammes per litre in order to avoid breakdown of the anodic

FIG. 3.

film and local attack on the metal during treatment in the normal manner. Firm connection by means of aluminium or duralumin wire is then made to the positive rail. In addition, it is essential that drum-tight contact be made with the article itself. Loose contact results in the lead becoming coated and as the anodic film is of an insulating character, the flow of current to the article is stopped and likewise the building up of the film. Furthermore, if the contact is sufficiently loose to permit movement, due to agitation of the solution, there is every danger of the scraping action causing arcing across the open faces with resultant fusion of the metal.

Operators should pay particular attention to this point, bearing in mind the relative insignificance of the coat of anodising to the value of, say, a precision finished component.

To ensure this tightness of contact calls for no little ingenuity in devising suitable clips with a fair degree of interchangeability.

Small articles may be conveniently treated, if bound tightly upon harl-hard aluminium wire of 18 or 19 s.w.g. and then hung in the bath in small batches through which the solution may freely circulate. Advantage should be taken of

any springiness in the article itself to keep the wiring taut throughout the period of treatment, it may even be advantageous to wire in two's or three's to create the effect of a spring. Very small articles can be successfully treated if packed tightly in a perforated aluminium container, the size of the container being in proportion to the size of the article; thus rivets $\frac{1}{16}$in. diameter by $\frac{1}{4}$in. long would require a container no bigger than a small teacup, and others $\frac{1}{8}$in. diameter by $\frac{3}{8}$in. long—tumbler size and so on. It is useless to attempt bulk quantities of small articles in large containers.

At the other end of the scale, occasion may arise when the article to be processed may be made its own treatment tank as in the case of large transport tanks which require internal coating only, as a protection against the effects of varying grades of fuel. The manner in which these transport tanks are treated is shown in the following photographs. It will be appreciated that in treating the compartments of these tanks there is a considerable rise in the temperature of the solution, and it is advisable to change the solution for each compartment by drawing from several reservoirs of acid. In addition to treating these tanks before assembling on the vehicle, treatment may be carried out when the tank is in position as the second photograph shows.

FIG. 4.

FIG. 5.

Exceptionally long articles may be treated in two operations by double immersion, the middle portion thus receiving two treatments due to the overlapping. The effect of this is to leave a semi-transparent band across the surface of the metal corresponding to the solution level during the second immersion. This transparency is even more noticeable in the case of large welded fuel tanks subjected to immersion in boiling water to remove flux after welding the second end into position. Isolation of the film where transparent has proved it to be perfectly regular. At this point I must emphasise that the line of transparency corresponding to the solution level in the second immersion is the line of points where pitting, due to various factors in the solution itself, is most likely to occur and inspection round this transparent line should be thorough.

From the necessity of tight contact we deduce the fact that every treated article has a bare point somewhere; the wirer's job is to see that such points are minimum in area and situated where least objectionable, yet great enough to allow of sufficient amperage flowing to the surface under treatment.

All material suspended in the bath and connected to the positive side of the circuit must consist of aluminium or an aluminium alloy. Brass or copper parts dissolve rapidly. Steel parts prevent the raising of the voltage by absorbing most of the amperage, which in turn may fuse the suspension wires and cause the

article to drop to the bottom of the bath. So far no effective means of " stopping off " other than keeping non-aluminium parts clear of the solution have been discovered.

Agitation of the solution by means of chain-driven paddles or air pumps is necessary in order to dispense local heat and to free oxygen bubbles forming on the work, because where such bubbles cling, the coating will not form. When suspending articles in the bath they should be so arranged as to admit the free escape of such bubbles to the surface. Designers might also bear this point in mind and avoid enclosures where gas is likely to be trapped.

Parts under treatment should be evenly distributed throughout the length of the bath so that concentration of current is uniform and consequently no abnormal local heating occurs. The insulating character of the anodic film has already been referred to, and, as the film and not the electrolyte constitutes the principal resistance to the circuit, heat is generated and dispersed from the surface, having risen in a convection current. Agitation which need not be violent will distribute this heat throughout the body of the solution and enable the normal raising of the voltage without breakdown of the surface of the metal and consequent porosity of the film.

When an enclosed vessel, such as a fuel tank, is under treatment, agitation of an irregular nature is imperative to prevent impurities in the solution remaining fast at any point upon the aluminium surface, otherwise these impurities, acting as cathodes in themselves, are most likely to set up arcing at the solution level.

FIG. 6.

Filtration, while beneficial in removing grease and substantial impurities, is ineffective in dealing with fine particles of alumina throughout the solution. If the volume of solution within the enclosed vessel or fuel tank is limited and if, in particular, only a limited area of internal cathode is possible, the solution should be free to flow or made to flow by pumping to the cooler solution outside. This measure prevents excessive difference in temperature which might be anything between 40 degrees C. and 100 degrees C., a circumstance which would almost certainly result in pitting.

Originally cathodes consisted of carbon, but experience has proved that the life of the chromic acid is prolonged by the use of stainless steel, and that less spray is formed at the anode by such means. Cathode surface should be at least equal to that of work under treatment and an ideal surface would be a treatment tank of stainless steel sheets welded together. The cost, however, of such a tank would be considerable, and treatment tanks are usually of mild steel, the cathode consisting of stainless steel sheets suspended around the side of the tank. Heating of the solution may be by gas burners or preferably by a system of steam and water pipes for control of temperature.

Evaporation losses should be made good each morning.

Before loading the bath consideration must be given to the nature of the material to be processed. Good aluminium sheet requires a current density of

3-3½ amperes per square foot of surface, although polishing before treatment tends to reduce the current density and, in addition, gives a more pleasing finish and a more uniform coating. On the other hand, material which has been roughened by sand-blasting, frosting or abrasion may require up to 6 amps. per square foot. Built-up fittings joined together by rivets or welding can be treated satisfactorily, although in the case of the former a little higher current density than the surface area would indicate is necessary, due possibly to a certain amount of local heating at the close joints, and particularly if the components have passed through the normalising bath in the course of production.

Conditions at the bath being satisfactory, it only remains to connect with the source of E.M.F., the usual unit being a direct coupled motor generator with separate excitation to ensure control at low voltages. In addition to the usual main and set switch fuses with motor starter, it is advisable to have a trip switch on the output side so that the switch, being set to trip at a safe load, no damage may be done to the electrical equipment by accidental overloading in the bath, *e.g.*, short circuiting caused by an article under treatment coming into contact with the side of the bath, the agitator, etc.

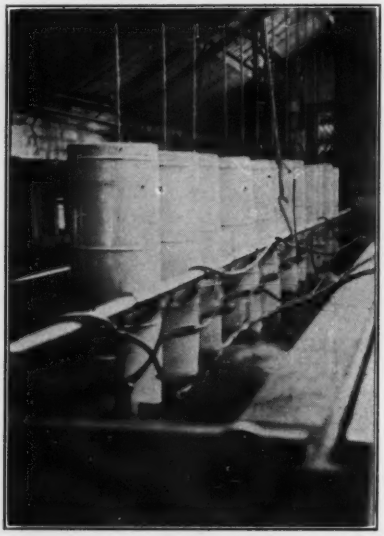


FIG. 7.

By means of finely graded resistance the voltage to the bath is raised from zero to 40 volts in 15 minutes, held at 40 volts for 35 minutes, raised a further 10 volts in five minutes, and maintained at 50 volts for the last five minutes of the hour when the treatment is completed. The article is then thoroughly washed in cold running water, immersed in hot water, and then allowed to drain and dry. Galvanised tanks for washing should not be used, lead lined or painted steel with a lining of fabric being much more suitable.

In the case of built-up fittings and castings, repeated washings in hot water and the application of a water gun may be necessary to get rid of chromic acid lodging in crevices and pores, oozing therefrom during drying off and staining the film. This staining, while not detrimental to the film, is unsightly, but, on the other hand, may serve the purpose of detecting the presence of cracks in

material, porosity of welds and other flaws. This has been found to be a distinct help in the final inspection of airscrews.

Fig. 9 indicates the relationship between amperage at higher and lower temperatures than the normal. It will be observed that current density is much higher than normal when overheating takes place, and readings of the ammeter and voltmeter will show a steady climb in amps. and a dropping in voltage so that when the final raising of voltage by 10 volts is due, sufficient amperage may not be available even to maintain at 40 volts. Even with unlimited amperage, the position would merely be further aggravated in greater heating and certainty of pitting, especially in the case of duralumin.

On the other hand, the lowering of the temperature gives a much lower current density resulting in the formation of a semi-transparent film. The experienced operator, knowing his load and dynamo, and with eye on the ammeter is generally able to detect unusual current rise or fall and take steps to correct the fault. Should the temperature be right to $\pm 2°C.$, low ammeter readings recorded and thin film result, then deterioration of the bath is indicated.

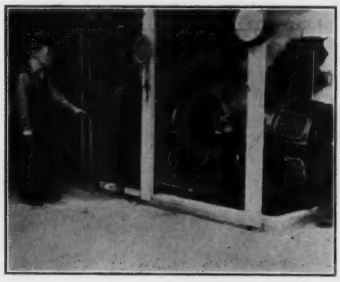


FIG. 8.

On account of an increasing concentration of alumina, iron oxide and matter disintegrated during the treatment of unsuitable alloys, the chromic acid becomes reduced and weaker in effect. The simplest method of checking the effectiveness of the solution while production progresses is to insert test strips of aluminium foil at each end of the bath every load. These test strips may thereafter be marked with date and time to correspond with the record of all material treated in that load, and filed for future reference.

A further test by hydrometer which initially records $4\frac{1}{2}$ in new solution may be made and until this reading reaches 8, it is the usual practice to add about 2 ozs. of new chromic salts per gallon per week. When the solution reaches this maximum density of 8, the addition of further acid gives only temporary effect, and the earliest opportunity of renewal should be taken.

The anodic process can be applied to aluminium, duralumin and most aluminium alloys, but where more than 5 per cent. copper is present, the current consumption is high, and breakdown occurs around 30 volts. Similarly, the treatment of castings requires a higher current density than aluminium, and much depends upon the condition of the surface; thus, machined silicon alloy or Alpax is more favourable than sand castings, the proportion of amperages required being 2-1.

The demand for anodically treated aluminium, particularly in architectural or decorative spheres, has greatly encouraged aluminium interests in this country to produce alloys of highest mechanical properties, combined with sympathy to anodic treatment, and a large range of such alloys has been produced under the trade names of Noral and Hyduminum. These alloys have been produced in cast and extruded form suitable for fabrication by riveting or welding.

The appearance of the film upon aluminium is greyish white, that on duralumin sheet grey; on machined duralumin bar the appearance is frequently of a pleasing mottled appearance, while treatment of silicon alloy results in production of a slate blue colour. Dr. Sutton has succeeded in isolating the anodic film. With regard to the weight and thickness of the film, the normally produced film has been found to weigh approximately 0.002 grammes per square inch, while the thickness is in the region of 1 u.

There is no appreciable difference in the size of the article after treatment; a small amount of weight is lost, but is compensated for by the growth of the film. Screwed articles, however, should be greased before assembly, owing to the dryness of the film tending to seizure. With regard to the mechanical properties of duralumin and aluminium sheet after treatment the tensile strength is not influenced. Apart from very thin material the embrittling effect of the treatment as observed in bend tests is unimportant.

The usual method of testing the value of the anodic film by applying a dye to the surface of the article leaves much to be desired in so far that films of varying density produced under varying conditions of solution, voltage and time may also be dyed to a greater or lesser degree, so that this method, at the best, is arbitrary. It has already been noted that colouration should immediately follow treatment owing to the hardening of the film by ageing. To apply a dye successfully for test purposes after treatment even upon a good film is therefore unsatisfactory.

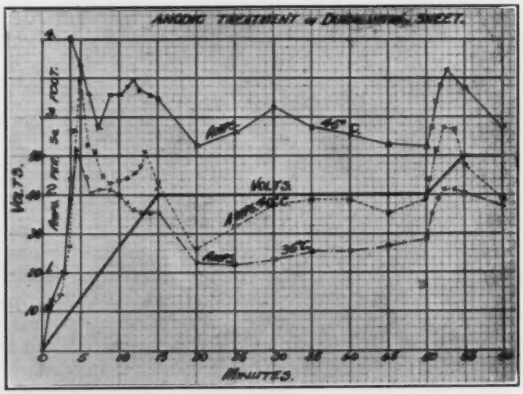


FIG 9.

A further test of electrical resistance of the film adds to the value of the first test, but is not conclusive.

Briefly, the testing set consists of a 100-volt dry battery with voltmeter with which a 1in. diameter steel ball and a sharp-pointed clip are connected on the positive and negative sides respectively. By scraping away a portion of the film, contact is made with the underlying metal on the negative side, the ball of the positive side being thereafter passed without pressure over the surface of the anodic film, and voltmeter readings, if any, recorded.

In the case of aluminium, insulation should be effective up to a potential of 70 volts, while the duralumin film should provide a barrier to 50 volts. Small impurities in the metal, however, may give lower readings, and this method can hardly be said to be satisfactory.

The involved tests of measurement by microphotography comes within the province of the laboratory expert, and is quite outside the capacity of the general run of operators.

On the other hand, the course of treatment laid down by authority lies within very narrow limits as to solution, temperature, voltage, control and time, so that if there is no deviation from these rules then, at the worst, there can be no bad films. In the hands of careful and experienced operators a system of visual comparison with a film of known value seems to be as good as any, and for that reason the inclusion of test strips of aluminium foil in every bath load meets the case from a practical standpoint. If wines, teas, coffee and so on can be safely left to test by palate, and colour shades to comparison tests under the eye of an expert, then we see no reason why the same principle, combined with the dye and electrical ball tests, should not be used in the case of anodic film.

The protective value of anodic films may be greatly enhanced by the application of lanoline in a suitable solvent such as benzine. This additional coating, being waterproof and very adherent, penetrates fine cracks in the metal which are the chief causes of breakdown in sea water conditions. In addition the anodic film forms a good base for paints and varnishes, these adhering much more strongly than to the untreated metal.

The fact that the film can be strongly coloured by immersion in suitable dyes is of interest, and a remarkable demand has grown up for such decorated material from architects, sign makers and fancy goods makers. The colours and pastel shades are most pleasing, and for all practical purposes nothing is added to the weight of the article so decorated. There is a distinct possibility of such colouration being put to a practical use in camouflage on the wings and fuselage of aircraft provided that the dyes used are fast to light, and matt in finish, giving a non-reflective finish.

In addition there appears to be a wide field for road signs, name-plates, wiring and other diagrams, while in the manufacture of camera and range-finder parts, the use of a dense non-reflective black dye will prove of considerable value.

A system whereby innumerable small components in store could be coloured according to their material specification would assist inspection, prevent mixing and greatly reduce the worries of harassed storekeepers.

Care should be taken in handling freshly treated goods; the film is tender and will suffer from abrasion, but ageing tends to harden it, making belated colouration difficult. To be successful, colouration should immediately follow treatment.

The alternative process of oxidation in dilute sulphuric acid is being operated chiefly by alumilite and Sheppard interests, the former being of American origin. Briefly, these processes consist of making the article the anode in a suitable bath containing weak sulphuric acid, through which a constant voltage of 12 volts in the case of aluminium, and 10 volts for duralumin, is passed for 50 minutes. This process results in a hard transparent coating which can be strongly coloured, and seems to possess advantages in so far that the fim, being less opaque than the Bengough film, imparts a liveliness of colour which is more attractive. Further, one may obtain a greater range of pastel shades, not possible in the chrome film without sacrifice of its corrosion resisting qualities. In addition, the sulphuric acid being colourless, it is less troublesome in the case of porous castings or built up fittings. Nevertheless, there is a wide field of application for both processes, the mechanical difficulties being in no way insurmountable. By comparison, the chromic film is much more ductile than that obtained by sulphuric acid, a property which in some cases is advantageous. On the other hand, the hard film may be advisable in some work, as in the case of motor pistons and other working faces.

Home Office regulations regarding operators of anodic baths become more stringent, not without good cause. Injury to the nasal membrane is certain unless the spray formed during treatment is extracted. It is advisable to close the top of the bath by means of a hood, roller blind, or other cover to assist extraction,

and keep the shop free of noxious fumes. Rubber gloves and aprons should be worn by those working at the bath, at the washing tanks or handling wet articles or clipping jigs.

The slightest scratch should not be neglected or it will result in a chrome sore requiring months to heal with incapacity of the workman affected. Unfortunately, even the best man is apt to ignore this warning, and only learns his lesson by painful experience. When chrome sores are encountered, the affected part should be thoroughly cleansed and a suitable ointment, of which there are several excellent varieties, applied, and covered by a bandage and kept dry. Similarly, a whiff of acid spray should be countered by rinsing out the nose with a luke warm solution of equal parts of sodium bichromate, sodium chloride, and the ointment worked well into the nostrils by means of cotton wool and a match stick.

In addition to anodic oxidation of aluminium, attempts have been made similarly to treat steel in a solution of lead nitrate and ammonium nitrate, but while this process gives a thick black coating of pleasing appearance, and a certain resistance to corrosion, wet conditions play havoc with the film and necessitate a secondary coating of grease.

A process of anodic oxidation of magnesium alloys has recently been noted in one of our technical journals, the electrolyte consisting of sodium dichromate and monosodium phosphate heated to 50 degrees C., and a current density of 5-10 amps. per square foot. Full details of performance are not, however, available.

RELAXATION AND ITERATION.

By J. Morris, B.A.

§1. Introduction.

In recent years much attention has been devoted to what Professor Southwell has appropriately called relaxation (1) methods in the solution of structural problems. These methods are essentially physical applications of iteration processes for solving simultaneous equations. In this paper it is not intended to discuss the advantages or otherwise of physical relaxation as compared with analytical iteration. The object is to examine the mathematical basis of the relaxation methods and to investigate the conditions of their convergency.

§2. The Derivation of Structural Equations.

For a stable structure subject to Hooke's Law and for which the external forces form a conservative system the potential or strain energy can be expressed as

$$V = \tfrac{1}{2}\,(a_{11}x^2 + 2\,a_{12}xy + a_{22}y^2 + \ldots)$$

where a_{11}, a_{12}, a_{22} . . . , are physical constants relating to the structure and x, y, z . . . , are displacements at the points of application and in the directions of the external forces.

For a stable structure V is clearly a positive homogeneous function of the second degree and in these circumstances it can be proved that

$$\begin{gathered} a_{11},\ a_{22},\ a_{33} \ldots, \text{ are positive,} \\ a_{11}a_{22} - a_{12}^2,\ a_{11}a_{33} - a_{13}^2 \ldots, \text{ are positive,} \\ \begin{vmatrix} a_{11}, & a_{12}, & a_{13} \\ a_{12}, & a_{22}, & a_{23} \\ a_{13}, & a_{23}, & a_{33} \end{vmatrix} \text{ etc., are positive,} \qquad \ldots\ldots\ldots \quad \text{(A)} \end{gathered}$$

and so on (2).

The structural equations will be given by

$$\begin{aligned} \partial V/\partial x &= F_1 = a_{11}x + a_{12}y + a_{13}z + \ldots \\ \partial V/\partial y &= F_2 = a_{12}x + a_{22}y + a_{23}z + \ldots \end{aligned}$$

and so on, where F_1, F_2, etc., are the external forces.

§3. Application of Iteration Process.

To restrict the problem we will consider a system of three external forces. The appropriate equations will thus be

$$\begin{aligned} a_{11}x + a_{12}y + a_{13}z &= F_1 \\ a_{12}x + a_{22}y + a_{23}z &= F_2 \\ a_{13}x + a_{23}y + a_{33}z &= F_3 \end{aligned}$$

To solve these equations by iteration we may put $y = 0$, $z = 0$, in equation F_1 and so determine x_1 the first approximation to x. Next we may put $z = 0$ in equation F_2 and use the value x_1 for x and so obtain y_1 the first approximation to y. Next, using the values x_1, y_1, already found, we obtain a value for z_1 from equation F_3. We now return to equation F_1 and make use of the values y_1, z_1, and thus find x_2 the second approximation to x. The process continues in this fashion until the successive values of the x's, y's and z's thereby found differ by as small amounts as may be prescribed. These values are then the solutions required. A convenient tabular process for effecting the iteration process by

differences of successive values of the variables which corresponds more nearly to the physical process of relaxation was given by the author in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY (3).

§4. CONVERGENCY OF ITERATION PROCESS.

Now it is clearly important that if the process is to be of any practical use it should be convergent and in this connection it appears that the conditions (A) which hold good for a stable structure are the necessary and sufficient conditions for the convergency of the iteration process if performed on the scheme outlined above.

Taking the case of three variables it has been shown (4) that for this process to be convergent the " characteristic " equation in λ, viz. :—

$$\begin{vmatrix} a_{11}\lambda, & a_{12}, & a_{13} \\ a_{12}\lambda, & a_{22}\lambda, & a_{23} \\ a_{13}, & a_{23}, & a_{33} \end{vmatrix} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (B)$$

must have its roots numerically less than unity if real and if imaginary roots occur then the moduli of conjugate pairs must be less than unity.

It would appear that when conditions (A) are satisfied then the roots of the characteristic equation will be appropriate for convergency. The proof for the general case does not seem to be evident, but it can readily be proved as follows for the particular case of three variables.

Let

$$a_{12}^2/(a_{11}a_{22}) = r_{12}^2,$$
$$a_{23}^2/(a_{22}a_{33}) = r_{23}^2,$$

and

$$a_{13}^2/(a_{11}a_{33}) = r_{13}^2.$$

Then r_{12}^2, r_{23}^2, r_{13}^2 are each less than unity. Thus r_{12}, r_{23}, r_{13} will each be less than unity, but will not necessarily be positive. In these circumstances equation (B) may be written

$$\begin{vmatrix} \lambda, & r_{12}, & r_{13} \\ r_{12}\lambda, & \lambda, & r_{23} \\ r_{13}, & r_{23}, & 1 \end{vmatrix} = 0$$

This determinantal equation on expansion becomes

$$f(\lambda) = \lambda^2 - (r_{12}^2 + r_{23}^2 + r_{13}^2 - r_{12}r_{23}r_{13})\lambda + r_{12}r_{23}r_{13} = 0.$$

Now $f(+1)$ will be positive since the determinant

$$\begin{vmatrix} a_{11}, & a_{12}, & a_{13} \\ a_{12}, & a_{22}, & a_{23} \\ a_{13}, & a_{23}, & a_{33} \end{vmatrix}$$

is positive.

Also $f(-1)$ is clearly positive.

Again

$$r_{12}^2 + r_{23}^2 > 2 \mid r_{12}r_{23} \mid > 2 \mid r_{12}r_{23}r_{13} \mid.$$

Similarly

$$r_{23}^2 + r_{13}^2 > 2 \mid r_{12}r_{23}r_{13} \mid,$$

and

$$r_{13}^2 + r_{23}^2 > 2 \mid r_{12}r_{23}r_{13} \mid.$$

$\therefore$ by addition

$$2(r_{12}^2 + r_{23}^2 + r_{13}^2) > 6 \mid r_{12}r_{23}r_{13} \mid$$

or

$$r_{12}^2 + r_{23}^2 + r_{13}^2 - \mid r_{12}r_{23}r_{13} \mid > 2 \mid r_{12}r_{23}r_{13} \mid.$$

Hence

$$r_{12}^2 + r_{23}^2 + r_{13}^2 - r_{12}r_{23}r_{13}$$

must be positive. Two cases arise

CASE I.

$r_{12}r_{23}r_{13}$ positive.

(1) *Roots Real.*

$$r_{12}^2+r_{23}^2+r_{13}^2-r_{12}r_{23}r_{13}$$

is positive and

$$> 2\sqrt{(r_{12}r_{23}r_{13})}.$$

$$\therefore\ r_{12}^2+r_{23}^2+r_{13}^2-r_{12}r_{23}r_{13}=2\sqrt{(r_{12}r_{23}r_{13})}+p^2$$

where p^2 is a positive quantity.

In these circumstances $f(\lambda)$ may be written as follows:—

$$f(\lambda)=\lambda^2-\{2\sqrt{(r_{12}r_{23}r_{13})}+p^2\}\ \lambda+r_{12}r_{23}r_{13}$$

or

$$f(\lambda)=(\lambda-r_{12}r_{23}r_{13})^2-p^2\lambda.$$

Thus $f(+1)$ is positive,

$$f\{+\sqrt{(r_{12}r_{23}r_{13})}\}\ \text{is negative,}$$

and $f(0)$ is positive.

Hence the two real positive roots are between 0 and $\sqrt{(r_{12}r_{23}r_{13})}$ and between $\sqrt{(r_{12}r_{23}r_{13})}$ and 1 respectively.

(2) *Roots Imaginary.*

Product of two roots $=r_{12}r_{23}r_{13}$ which is less than unity.

Hence the modulus of the conjugate pair of imaginary roots is less than unity.

CASE II.

$r_{12}r_{23}r_{13}$ negative.

In this case

$f(-1)$ is positive,

$f(0)$ is negative,

and

$f(+1)$ is positive.

Thus there will be two real roots, one between -1 and 0 and the other between 0 and $+1$.

If there are four variables then the "characteristic" equation in λ will be

$$\begin{vmatrix} \lambda, & r_{12}, & r_{13}, & r_{14} \\ r_{12}\lambda, & \lambda, & r_{23}, & r_{24} \\ r_{13}\lambda, & r_{23}\lambda, & \lambda, & r_{34} \\ r_{14}, & r_{24}, & r_{34}, & 1 \end{vmatrix}=0$$

and so on for any number of variables. The proposition evidently holds good for two and three variables. That it holds good for any number would appear to be the case, but the writer is unable to prove it generally. It occasionally happens that a general proposition may be inferred on physical grounds, but is not readily proved algebraically.

§5. IMPORTANCE OF SCHEME OF ITERATION ON CONVERGENCY.

The convergency or otherwise of an iteration process depends on the scheme adopted for the iteration. For example, taking the three equations of §3 the scheme of iteration so far discussed is symbolised by

$$a_{11}x_n+a_{12}y_{n-1}+a_{13}z_{n-1}=F_1$$
$$a_{12}x_n+a_{22}y_n+a_{23}z_{n-1}=F_2$$
$$a_{13}x_n+a_{23}y_n+a_{33}z_n=F_3$$

and the appropriate "characteristic" equation in λ is given in §4, viz.,

$$\begin{vmatrix} a_{11}\lambda, & a_{12}, & a_{13} \\ a_{12}\lambda, & a_{22}\lambda, & a_{23} \\ a_{13}, & a_{23}, & a_{33} \end{vmatrix}=0$$

If, however, the following scheme of iteration is adopted, viz.,

$$a_{11}x_n + a_{12}y_{n-1} + a_{13}z_{n-1} = F_1$$
$$a_{12}x_{n-1} + a_{22}y_n + a_{23}z_{n-1} = F_2$$
$$a_{13}x_{n-1} + a_{23}y_{n-1} + a_{33}z_n = F_3$$

then it may be shown that the " characteristic " equation in λ will be

$$\begin{vmatrix} a_{11}\lambda, & a_{12}, & a_{13} \\ a_{12}, & a_{22}\lambda, & a_{23} \\ a_{13}, & a_{23}, & a_{33}\lambda \end{vmatrix} = 0.$$

To take a numerical example let

$$r_{12} = 0.884,\ r_{23} = 0.953,\ r_{13} = 0.770;$$

then the first " characteristic " equation is

$$\lambda^2 - (r_{12}^2 + r_{23}^2 + r_{13}^2 - r_{12}r_{23}r_{13})\,\lambda + r_{12}r_{23}r_{13} = 0,$$

the roots of which for the given value of the r's are found to be

$$\lambda_1 = 0.680,\ \lambda_2 = 0.954;$$

and the process is therefore convergent.

The second " characteristic " equation will be

$$\lambda^3 - (r_{12}^2 + r_{23}^2 + r_{13}^2)\,\lambda + 2\,r_{12}r_{23}r_{13} = 0,$$

the roots of which for the given values of the r's are found to be

$$\lambda_1 = 0.765,\ \lambda_2 = 0.975,\ \lambda_3 = -1.740.$$

Since one of these roots is numerically greater than unity the corresponding iteration is, in consequence, divergent.

References.

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2. Differential calculus. Williamson. Chap. XVI.
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ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS

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(Prepared by R.T.P.)

No. 56. JUNE, 1938.

Dollar Values in Airplane Design. (K. Perkins, Journal of Aeron. Sciences, Vol. 4, Feb., 1937, pp. 139-148.) (56/1 U.S.A.)

In view of the present interest in mass production, attention is called to an equation proposed by the author for determining manufacturing cost.

Cost per aircraft in dollars

$$= [WA/qn + pB + WC/qs\,(1+b)]\,(1+r/q)$$

where W = complete empty weight of aircraft (lb.).
q = number of machines built in one lot.
p = total rate brake horse-power.
B = cost of engine with all accessories and instruments (per b.h.p.).
C = cost of labour for one aeroplane per lb. weight.
A = cost of material for one aeroplane per lb. weight (excluding engines and instruments).
b = ratio of factory overhead to direct labour cost.
r = ratio of total development cost to production cost per aeroplane.

In the case of all-metal military aircraft

$B = 15$; $b = 0.9$;
$C = 5.6$; $r = 5$;
$A = 1.2$;
n = material quantity exponent = 0.075;
s = labour quantity exponent = 0.30.

Taking 100 machines, this becomes, per lb. of aircraft:—

Cost of material = \$1.7.
Cost of labour = \$1.4.
Cost of overhead = \$1.3.
Total cost of frame = \$4.4 per lb.
= 17/6.

(See also Abstracts No. 42, item 12.)

On the Maximum Error in a Series and the Dispersion of a Volley. (O. v. Eberhard, Z.A.M.M., Vol. 18, No. 2, April, 1938, pp. 128-35.) (56/2 Germany.)

The author shows, in the case of m series of observations, how to calculate the probable error of the single observation from the maximum apparent error of each of the m series. The same method is applied to the determination of the probable error from the total dispersion obtained in m groups of hits.

On the Lessons to be Drawn from the Spanish Aerial War. (L'Aeronautique, Vol. 20, No. 227, April, 1938, pp. 69-70.) (56/3 France.)

1. There is no doubt that the various governments, supplying aircraft to Spain, have gained valuable experience as to the reliability and ease of maintenance under active service conditions.

2. The number of aircraft is much too small to enable any definite opinions being formed as to the possibility of obtaining a major decision by aircraft alone.

3. The conditions in Spain are peculiar in that poison gas has, so far, not been employed by either side.

The war can thus scarcely be classified as "modern," and any deductions have to be treated accordingly.

4. The fact that this is a civil war may account, to some extent, for the evident reluctance to subject large towns, such as Madrid, to a ruthless attack by all available means.

In a major war such an attack would be carried out by the simultaneous action of 3-4,000 aircraft. (It is estimated that the whole of the air force available in Spain does not amount to more than 700 machines on either side).

A New Type of Aerial Mine. (Kjerstrom, U.S. Nav. Inst. Proc., Vol. 64, No. 5, May, 1938, p. 765.) (56/4 Sweden.)

A new type of aerial mine has been invented by the Swedish engineer Kjerstrom. These mines are suspended under captive balloons whose height and situation can be controlled from the ground. They are fitted with an apparatus for detonation by means of high frequency radio waves. The mines are to contain one of the following ingredients: high explosive; poison gas; smoke; or metal dust. The latter is favoured, as it covers so much territory, and is guaranteed to ruin any aeroplane engine which comes into contact with the dust. Metal dust filling for shells is also to be used with anti-aircraft guns.

Lessons from the Spanish Aerial War. (A. Langeron, Les Ailes, No. 884, 26/5/38, p. 11.) (56/5 France.)

The following are the main conclusions:—

(1) There is no danger from A.A. artillery at 6,000 m. It is essential that the crew be protected against the cold at altitudes of this order.

(2) Armour plating, fitted to the back and seat, has proved very effective in protecting single-seater fighters.

(3) The result obtained by the relative small number of aircraft employed in Spain indicate that the air arm may, by itself, force a decision provided sufficient machines are available (several thousands).

(4) Superiority of speed is of paramount importance, not only from the tactical point of view, but also, because it raises the morale of the aircraft crew.

Formation Flying for Bombers. (C. Pigeon, Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 366-378.) (56/7 France.)

From the point of view of defence against fighters, the author recommends:—

(1) The bombers fly in a plane inclined forward at an angle of approximately 15° with the vertical.

(2) The formation in this plane is in the form of a symmetrical figure (flattened polygon).

(3) The maximum span of the formation (width at right angles to trajectory) must not exceed 200 m.

When attacking an objective defended by A.A. artillery, the formation should be such that successive aircraft pass the target under different bearing angles. This entails a spreading out of the formation from that previously adopted against fighters. Examples of suitable manœuvres are illustrated.

The Military Application of Light Aeroplanes. (Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 363-5.) (56/6 France.)

There is no doubt that light slow speed aircraft, operating at feeble altitudes in proximity to artillery positions, would be very useful for spotting purposes. It appears, at first sight, as if the " autogiro " would fulfil all requirements in this direction. Recently, however, fixed wing aircraft have been designed which approximate closely to the " autogiro " performance with the additional advantages of greater mechanical reliability and pay load. A specification for such an aircraft would be the following:—

Normal altitude	300 m.
Time to reach this	2 minutes.
Max. speed	190 km./h.
Min. speed	50 km./h.
Landing run	70 m.
Take-off run	150 m.
Endurance	2 hours at cruising speed.
Armament	Nil.
Useful load	250 kg. (pilot, observer, wireless).

It appears that Germany is designing aircraft of this type.

The " autogiro " would, however, be very useful for Red Cross work near the front line (collection of wounded, etc.), and since this type of aircraft is easily distinguished, the author enters a plea for its international recognition for work of this nature.

Armament Patents Purchased by the Junkers Firm. (Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 475-478.) (56/8 Germany.)

The two patents (No. 676,264 and 751,572) were originally taken out by F. Mannebach in 1929 and 1933, respectively.

The former refers to a pivoted gun mounting in aircraft characterised by the fact that the weight of the operator, sitting on a portion of the mounting, is practically balanced by the weight of the gun. The elevation of the gun is, thus, controlled by a slight leg action whilst orientation in a horizontal plane is effected by a servo motor. The second patent refers to gun operation at high altitude, the operator being in a sealed cabin with the gun outside. Various types of control mechanisms for the gun are described.

Military Aspects of Civil Aviation. (C. Rougeron, Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 379-397.) (56/9 France.)

Commercial aircraft differs from other means of transport in that it is still available when other means may become impossible, due to enemy action (destruction of roads and railways, blockade of harbours). From the military point of view it has the additional advantage that the civil machine can be very easily transformed into an offensive weapon. It is therefore not surprising that civil aviation is subsidised by the various governments and severe restrictions are applied by certain countries as to landing and transit rights. Unlike the sea, which is free to all, the air is becoming nationalised and unless international agreement is reached, it appears quite possible that a country possessing favoured air routes may be able, in the future, to derive sufficient commercial revenue by forcing out competitors to defray a considerable proportion of its military budget.

Aircraft Armament Research in 1910-11. (L. C. Bellenger, Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 398-424.) (56/10 France.)

The author gives a most interesting account of work carried out at Vincennes, in the year 1910, under the general direction of Col. Etienne. It appears that the first official bomb dropping experiments were carried out that year in the

U.S.A. It was soon realised that the chance of hitting a restricted military target was very small, whilst the indiscriminate bombing of civilians in towns was considered contrary to international law.

As the restricted weight carrying capacity of aircraft of this period prevented the dropping of a sufficiently large number of bombs to allow for dispersion, attention was given to an alternative, the light weight metal dart. It is interesting to note that at this period, a proposal to fit a machine gun to the aircraft was turned down by the French War Office, partly because it was thought to endanger the structure of the aircraft and partly because it interfered with what was considered the primary duty of the aircraft crew, *i.e.*, ground observation.

Some Contracts Placed by the U.S. Army Air Corps in 1937. (Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 459-460.) (56/11 U.S.A.)

The following are the average prices paid, per machine, and include spares:—

Type	Number ordered	Cost per machine
Sikorsky Amphibian S.43	6	£21,000
Boeing B.17 4-engined bomber	13	£38,000
Douglas 2-engined bomber	177	£13,000
North American Trainer	73	£2,400
North American Fighter	95	£3,200
Curtiss Fighter P.36	210	£4,000
Douglas Fighter A.17A	29	£4,400
North American Reconnaissance	55	£6,000
Kellet Autogiro	6	£8,000

The Choice of Calibre for A.A. Artillery. (R. Maurer, Rev. de l'Arm. de l'Air, No. 105, April, 1938, pp. 433-436.) (56/12 France.)

At the present moment there exists two distinct classes of A.A. artillery; long range guns using explosive shells fitted with time fuses and short range guns using percussion ammunition.

It is obvious that the chance of hitting fast moving aircraft depends on the time taken for the projectile to reach the target, the type of shell (*i.e.*, whether a direct hit is required or whether an explosion in the close proximity suffices) and the rate of fire. There is no doubt that for altitudes above 4,000 m., calibres in excess of 3in. are required, the shell being fitted with a time fuse. In this case the necessary rate of fire is obtained by grouping a number of guns. It has been suggested that all altitudes below 4,000 m. can be successfully covered by automatic guns of 1.5in. calibre.

The author, however, points out that these light weight projectiles are not ballistically efficient and that the increase in rate of fire is not sufficient to compensate for the increase in dispersion. Time fuses on such small shells are not satisfactory, and an urgent plea is entered for the retention of 3in. calibre guns for altitudes between 2,000-3,000 m., the smaller calibre 1-1.5in. being used for altitudes below this.

The provision of three types of guns necessarily complicates the equipment of the A.A. artillery, but it is held that this is unavoidable.

Fighters v. Modern Bombers. (C. Pigeon, Rev. de l'Arm. de l'Air, No. 103, February, 1938, pp. 125-142. Available as Translation No. 649.) (56/13 France.)

The author investigates the case of a fighter attacking bombers from the rear. Mutual fire is assumed to start at a distance of 600 m., the fighter gradually overtaking the bomber. Depending on the number of guns in action, their rate of fire and dispersion as well as the relative size of the two targets, the difference in probability, of the fighter hitting the bomber or vice versa, reaches a maximum at some definite distance of approach. At this point the fighter breaks off the action and retreats, still keeping in line with the tail. After reaching the maximum distance of 600 m., the attack is repeated or the fighter replaced by a second machine.

The case of simultaneous attack by several fighters on one bomber formation is also considered as well as the relative advantages of cannon and machine gun. It appears that unless the bombers can maintain close formation at high speed, the fighter fitted with four machine guns constitutes a very dangerous adversary.

The general conclusion which may be drawn from the above is that high rate of fire is of the utmost importance.

Measurement of Wake. (F. Horn, Eng. Absts., Vol. 1, No. 3, Section 3, April, 1938, p. 21. Trans. of N.E.C. Inst. of E. and S., 31/3/38.) (56/14 Great Britain.)

The author discusses the analysis of wake into its various components—streamline, frictional and wave wake—and compares different methods of measurement. Evidence on the subject of scale effect, in going from the model to the ship, is cited and an expression for the relation between the streamline wake and the corresponding thrust deduction (to which must be added the frictional thrust deduction) is derived. The wake behind a ship model can be found, either indirectly from the model screw results, or directly, by means of blade wheels or pitot tubes. In the former case the results may differ according to whether the thrust or torque values are utilised, and in the latter there are different methods of averaging over the disc, which do not all yield identical results. As regards the relation between the directly and indirectly determined values, the torque wakes are stated to be generally in fair agreement with the volume mean of blade-wheel or pitot tube readings. The ship frictional wake is appreciably less than that of the model, but there is little direct evidence on other scale effects, a knowledge of which would allow a satisfactory correlation of model and ship results.

Aerofoil Sections in Screw Propellers. (J. F. Allen, Eng. Absts., Vol. 1, No. 3, Section 3, April, 1938, p. 21. Trans. of N.E.C. Inst. of E. and S., 31/3/38.) (56/15 Great Britain.)

Results of tank tests on lift, drag and pressure distribution are given for five sections: A, segmental; B, " Clark Y " aerofoil; C, modified segmental with rounded nose; D, sharp-nosed " Clark Y "; E, circular back " Clark Y " nose. The Reynolds number of the tests was 3.5×10^5, and all the sections had a thickness ratio 0.12. The sharp-nosed sections show high drag at low incidence, which is elucidated by means of the pressure plotting, and confirmed by certain model screw test results. Both the original and modified circular-back sections show a reduced lift-curve gradient at the higher angles of incidence. The maximum back-suction occurs nearer the nose and is greater in amount for the aerofoil sections than for the others. It is concluded that a well-rounded nose, and lifting the nose relative to the face gives good results. The maximum ordinate should, however, not be too far forward, as the high suction may produce cavitation.

Experiments on Water Waves of Translation in Small Channels. (J. Allen, Phil. Mag., Vol. 25, No. 170, 12/5/38, pp. 754-68.) (56/16 Great Britain.)

In an extremely tortuous channel a wave is propagated at a speed approximately as calculated from the depth of water measured along the deepest axis of the channel, and neglecting the speed of the stream in which the wave travels.

In straight channels of triangular cross-section the wave velocity is very closely equal to that calculated on the basis of the average depth. In trapezoidal channels, however, the effective depth is somewhat greater than the average.

In straight or comparatively straight and uniform channels a bore is propagated with velocity closely equal to

$$\sqrt{\{2g(h+k)^2/(2h+k)\}} - v,$$

where v is two-thirds of the maximum surface velocity indicated by a shallow float (or approximately the mean velocity over the cross-section) and h is the depth measured along the deep-water axis of the stream, k = height of wave crest above surface of stream. (Both v and h are measured just previous to the arrival of the bore.)

Possibilities of Error in Model Experiments on Vehicle Air Resistance. (C. Schmid, Z.V.D.I., Vol. 82, 19/2/38, pp. 188-194. Eng. Absts., Vol. 1, No. 4, Section 2, April, 1938, p. 58.) (56/17 Germany.)

The work of Flachsbarth, in continuation of the early experiments of Eiffel and of Prandtl, indicates that the air-resistance coefficient of a sphere, *e.g.*, of 150 mm. (6in. diameter), is practically constant with a Reynolds number exceeding 3.5×10^5. The author discusses the possibility of carrying out model experiments on cars in this super-critical range. The principal methods of suspending the model are as follows: (1) free; (2) on ground plane; (3) double reflected model with and without ground plane; (4) on a ground track moving at wind speed. The author summarises experimental values derived from experiments made at Gottingen and Stuttgart. He discusses the difficulty of making a model representative of the actual vehicle, with special reference to the air-flow through the radiator, around the wheels, and past windows and door-fittings.

The Theory of the Hele-Shaw Experiment. (F. Riegels, Z.A.M.M., Vol. 18, No. 2, April, 1938, pp. 95-106.) (56/18 Germany.)

This paper gives a solution of the Navier Stokes equations by a method of iteration in the case of a flow round a cylinder between parallel walls of small distance. (Hele-Shaw flow with inertia.) The flow is determined by a non-dimensional characteristic number which contains the Reynolds number and the ratio between the distance of the walls and the diameter of the cylinder. The results of the theory are verified experimentally.

On the Field of Flow Round a Thin Slightly Curved Aerofoil. (F. Weinig, Z.A.M.M., Vol. 18, No. 2, April, 1938, pp. 107-21.) (56/19 Germany.)

The motion of the air in the field of an aerofoil may be visualised by six systems of curves: Curves of equal direction of the motion and curves of equal velocity; curves of equal curvature of the stream-lines and curves of equal acceleration; curves where the change of curvature of the stream-lines is constant and curves of equal change of acceleration. In first approximation they are given by the real and imaginary parts of three functions of a complex variable, which are calculated by the author.

Theory of Active Anti-Rolling Tanks (G. Weinblum, Z.A.M.M., Vol. 18, No. 2, April, 1938, pp. 122-7.) (56/20 Germany.)

After discussing some examples of the heeling moments exerted on a ship by the waves (as given by the approximate (linear) theory), the author shows the

limits of validity of that theory and indicates some necessary developments. The ordinary " passive " anti-rolling tanks may be rendered more efficient by applying supplementary " active " forces. The different methods of activation are studied by means of the diagrams of amplitudes.

Boundary Layer in Compressible Fluids. (T. v. Kármán and H. S. Tsien, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 227-32.) (56/21 U.S.A.)

The first part of the paper is concerned with the theory of the laminar boundary layer in compressible fluids. The known solution for incompressible fluids is extended to large Mach's numbers by successive approximation. The compressibility effect on surface friction is discussed, and the results applied to estimate the ratio between wave resistance and frictional drag of projectiles and rockets. In the second part the heat transfer between a hot fluid and a cool surface, then between a hot body and a cool fluid is discussed. A general relation between drag and heat transfer as function of Mach's number is given. The limits where cooling becomes illusory because of the heat produced by friction are determined.

The Stability Problem in Hydrodynamics—II. (C. L. Pekeris, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 237-240.) (56/22 U.S.A.)

The author shows that parabolic flow of a viscous fluid between two fixed walls is stable for small disturbances which have symmetrical stream lines. Unsymmetrical disturbances have already been discussed in a previous paper (Proc. Camb. Phil. Soc., Vol. 32, 1936, p. 35), and it was shown that the damping in this case is greater than for the symmetrical disturbance.

It thus appears that the method of small oscillations is incapable of explaining the break down of parabolic flow, which occurs, in practice, as soon as certain range of Reynolds number is exceeded. Two possibilities are considered by the author:—

(1) The break down is due to finite disturbances.
(2) Instability of boundary layer in entrance region, *i.e.*, before parabolic flow is established.

Further researches will be required before this problem of stability can be considered as solved.

A Water Tank Model Tests on the Motion of Airships in Gusts. (A. Kuethe, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 243-4.) (54/23 U.S.A.)

A water tank and the auxiliary apparatus for determining the free motion of airships in gusts is described. The set-up is in operation at the Guggenheim Airship Institute and a series of tests, financed by the Navy Bureau of Aeronautics, is being carried out. The method utilises a water basin across a section of which a stream of water, simulating a gust, flows. An airship model immersed in the water and moved across the gust is free to turn and drift. The position and azimuth of the model are registered as functions of the time. The interpretation of the results in terms of forces and moments acting on the ship are discussed.

Determination of Profile Drag from Measurements in the Wake of a Body. (W. Bollay, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 245-8.) (56/24 U.S.A.)

Formulæ for the parasite drag from wake measurements corresponding to those by Betz and Jones have been deduced from basic principles. It is pointed out that Betz neglected quadratic terms of small velocities which, when measurements are carried out very close to the body, may introduce appreciable errors. Jones's formula does not suffer from this defect; in fact it should hold best close to the body before the wake has suffered much energy dissipation.

Both Jones and Betz neglected the quantity $\rho/2\ (v_1^2+w_1^2)$ in their formulæ as small, which should be justified experimentally. Jones's assumption of no energy loss in the wake appears reasonably good, but requires also more through experimental verification. It should also be verified whether the pressure in the turbulent wake is the same as that calculated from a pure potential flow. It is pointed out that the plane of measurements in the wake should be normal to the free stream velocity, otherwise a small correction should be introduced.

(See also (1) Profile Resistance Measurements in the Large Wind Tunnel of the D.V.L., H. Doetsch and M. Kramer, L.F.F., Vol. 14, pp. 173 and 371—available as translations No. 465 and 501. (2) Remarks on Profile Resistance Measurements at the D.V.L., H. Muttray, L.F.F., Vol. 14, p. 372—available as translation No. 500.)

The Increase in Frictional Resistance Caused by Various Types of Rivet Heads as Determined by Tests of Planing Surfaces. (S. Truscott and J. B. Parkinson, N.A.C.A. Tech. Note No. 648, May, 1938.) (56/25 U.S.A.)

The increase in the frictional resistance of a surface caused by the presence of rivet heads was determined by towing four planing surfaces of the same dimensions in the N.A.C.A. tank. One surface was smooth and represented a surface without rivet heads or one with perfectly flush countersunk rivets. The other three surfaces were each fitted with the same number of full-size rivet heads, but of a different type arranged in the same pattern on each surface. The surfaces were towed at speeds representative of the high water speeds encountered by seaplanes during take-off and the range of Reynolds number covered by the tests was from 4×10^6 to 18×10^6.

The rivet heads investigated were oval countersunk, brazier, and round for rivets having shanks 5/32 inch in diameter. The oval countersunk heads were sunk below the surface by dimpling the plating around them.

The results of the tests showed that, for the rivet heads investigated, the increase in the friction coefficient of the surface is directly proportional to the height of the rivet head. The order of merit in regard to low resistance is flush countersunk, oval countersunk (whether sunk below the surface or not), brazier, and round.

Pressure Distribution Over Aerofoils with Fowler Flaps. (C. J. Wenzinger and W. B. Anderson, N.A.C.A. Report No. 620, 1938). (56/26 U.S.A.)

A test installation was used in which the model was mounted in the wind tunnel (7 × 10 and 5-foot vertical) between large end planes so that two-dimensioned flow was approximated.

The data are given in the form of pressure distribution diagrams and as plots of calculated coefficients for the aerofoil-and-flap combinations and for the flaps alone. The pressure distribution tests show that the effect of increasing the chord of the Fowler flap (for a given lift of combined aerofoil and flap) is to increase the portion of the total load carried by the flap and to decrease the adverse pressure gradients of the main aerofoil and thereby its tendency to stall. The maximum values of the normal force coefficient of the Fowler flap were found to be much smaller than previously indicated and approximately the same as those of the external aerofoil flap and of the simple split flap. The flap load data given in this report supersede those given in Report No. 534.

Compressible Flow About Symmetrical Joukowski Profiles. (C. Kaplan, N.A.C.A. Report No. 621, 1938.) (56/27 U.S.A.)

The method of Poggi is employed for the determination of the effects of compressibility upon the flow past an obstacle. A general expression for the velocity increment due to compressibility is obtained. An application is made to the case of a symmetrical Joukowski profile with a sharp trailing edge, fixed in

a stream of velocity v_0 at an arbitrary angle of attack and with the circulation determined by the Kutta condition.

Since actual experimental data for Joukowski profiles are lacking, the theoretical results are applied to a thin and a thick profile at zero angle of attack, and the velocity and pressure distributions are calculated and compared with those for the corresponding incompressible cases. The critical values for the ratio of the stream velocity v_0 to the velocity of sound in the stream c_0 (corresponding to the attainment of the local velocity of sound c by the fluid on the surface of the aerofoils) are also obtained.

The Lift and Moment on a Flat Plate in a Stream of Finite Width. (T. H. Havelock, Proc. Roy. Soc., Series A, Vol. 166, No. 925, 19/5/38, pp. 178-96.) (56/28 Great Britain.)

The paper gives a new treatment of the problem of a flat plate in a stream bounded by plane parallel walls, including circulation round the plate. The plate is considered as the limiting case of the elliptic cylinder; an integral equation is obtained, whose solution by continued approximation leads to expansions for the lift and moment on the plate. The solution is modified to give similar results when the stream is bounded by parallel free surfaces, taking the condition of a free surface in an approximate form; and a further modification gives the case when one boundary of the stream is a plane wall and the other is a free surface. The problem of the elliptic cylinder in general is also considered with reference to the moment of the forces when the stream is bounded by plane walls and when there is no circulation.

Flight and Wind Tunnel Tests of an XBM-1 Dive Bomber. (P. Donely and H. A. Pearson, N.A.C.A. Tech. Note No. 644, April, 1938.) (56/29 U.S.A.)

Results are given of pressure distribution measurements made in flight over the right wing cellule and the right half of the horizontal tail surfaces of a dive-bombing biplane. Simultaneous measurements were also taken of the air speed, control surface positions, control forces, and normal accelerations during various abrupt manœuvres in a vertical plane. These manœuvres consisted of push-downs and pull-ups from level flight, dives and dive pull-outs, and push-ups from inverted flight.

In addition to the pressure measurements, flight tests were made to obtain (1) wing fabric deflections during dives and (2) variation of the minimum drag coefficient with Reynolds number. Supplementary tests were also made in the full-scale wind tunnel to obtain the characteristics of the aeroplane under various propeller conditions and with various tail settings.

The results indicate that: (1) By decreasing the fabric deflection between pressure ribs, the span load distribution was considerably modified near the centre and the wing moment relations were changed; and (2) the minimum drag was less for the idling propeller than for the propeller locked in a vertical position.

Some Aspects of the Stalling of Modern Low-Wing Monoplanes. (H. A. Soule and M. N. Gough, N.A.C.A. Tech. Note No. 645, April, 1938.) (56/30 U.S.A.)

Basically the stalling problem consists of the elimination of the rolling instability. The complete elimination of rolling instability, however, does not seem possible. It may be possible, nevertheless, to delay rolling instability to angles of attack that cannot be attained with conventional elevator controls.

The present emphasis on stalling characteristics is primarily a result of the high taper ratios and the low-wing positions employed on modern aeroplanes.

With small low-wing single-engine aeroplanes, the undoubted benefits obtained by the simplicity of retracting the landing wheels makes it probable that this

low-wing arrangement will be adhered to. With large transport aeroplanes, the wing height relative to the ground has become so large, owing to the increases in propeller diameter, that there is no need to keep the fuselage above the wing. Lowering the fuselage relative to the wing would, in addition to improving the elevator-force variation, have no effect on the retracting mechanism for the main wheels and, in the case of the level three-wheel landing gear, would simplify the installation of the front wheel.

Wind Tunnel Tests of a Two-Engine Aeroplane Model as a Preliminary Study of Flight Conditions Arising on the Failure of One Engine. (E. P. Hartman, N.A.C.A. Tech. Note No. 646, April, 1938.) (56/31 U.S.A.)

Wind-tunnel tests of a 15-foot-span model of a two-engine low-wing transport aeroplane were made as a preliminary study of the emergency arising upon the failure of one engine in flight. The added drag resulting from the unsymmetrical attitudes required for flight on one engine was determined for the model aeroplane.

The effects of the application of power upon the stability, controllability, lift, and drag of the model aeroplane were measured. A dynamic-pressure survey of the propeller slipstream was made in the neighbourhood of the tail surfaces at three angles of attack.

The added parasite drag of the model aeroplane, resulting from the unfavourable conditions of flight on one engine, was estimated to be approximately as follows:—

At ceiling, 30 per cent.
Full-throttle climb at sea level, 40 per cent.
High speed, 19 per cent.

From 35 to 50 per cent. of this added drag was due to the drag of the dead-engined propeller and the other 50 to 65 per cent. was due to the unsymmetrical attitude of the aeroplane. The mode of flight on one engine, in which the angle of sideslip was zero, was found to require less power than the mode in which the angle of sideslip was several degrees.

Lessons to be Drawn from Natural Flight and Their Application to the Problem of the Hovering Helicopter, with Some Remarks on the Helicostat. (E. Oehmichen and J. Tilbo, Comp. Rend., Vol. 204, No. 19, 9/5/38, pp. 1355-1359.) (56/32 France.)

The authors are of the opinion that the stability of insect or bird flight, when hovering, is largely due to the mass of the air associated with the motion of the wings. Similar stabilising effects can be obtained with a screw helicopter, working under hovering conditions, by attaching an air capacity to the machine in a suitable position.

This was demonstrated in 1935, the four helicopter screws being surmounted by a spherical balloon of 100 m^3 capacity filled with cold air. The available horse-power amounted to 40, and sufficed to lift the pilot to various altitudes between four and 20 metres, the heights being maintained entirely by engine power (no other control surfaces). In the present paper the authors suggest filling the stabilising volume with a lifting gas (H or He) the capacity being sufficient to reduce the rate of descent to 4 m./sec. with the engine cut out.

The gas assisted helicopter thus has to produce a smaller lift and will work at a correspondingly greater efficiency. By inclining the lifting screws forward, translation as well as lift will be obtained. A machine of this type is named Helicostat by the authors and it is claimed that it will be particularly suitable for operation in difficult colonial country (Forests).

Aileron Hinge Moments Utilised to Ensure Automatic Stability. (M. Victor, Les Ailes, No. 884, 26/5/38, pp. 8-9.) (56/33 France.)

Toussaint has already shown, in 1928, that the aileron hinge moment is a linear function of the deflection of the aileron and the incidence of the wing. Moreover, the lift is controlled by the aileron deflection, and since the inertia of the aileron is very small compared with that of the complete aircraft, a sufficiently rapid aileron control should enable the aircraft to maintain a steady course in gusty weather.

Recent experiments carried out under Toussaint's direction at St. Cyr, have shown that sufficient control force can be obtained with ailerons of normal size, by utilising a pivoted form of horizontal tail surface suitably interconnected with the aileron.

From the experimental figures it appears that the lift of a model, so equipped, will remain constant over large variations of air speed and incidence.—Note: The utilisation of aerodynamic forces for stability and lift control also forms the basis of the well-known Constantin Wind Vane Stabiliser.

Wind Tunnel Tests of a Clark Y Wing having Split Flaps with Gaps. (C. J. Wenzinger, N.A.C.A. Tech. Note No. 650, May, 1938.) (56/34 U.S.A.)

Tests were made in the N.A.C.A. 7- by 10-ft. wind tunnel of a Clark Y wing, having split flaps with a gap between the flap and the lower surface of the wing. Lift, drag, and pitching moments were measured for the wing with three different sizes of flap. It was found that any gap between the flap and the wing reduced the lift, the drag, and the pitching moments, but that the centre-of-pressure movement and the ratio of lift drag were little affected.

Measurement of Air Flow Over Cylinders having Very Small Distances between the Cooling Fins. (A. Berndorfer, Year Book of German Aeronautical Research, Vol. 2, 1937, pp. 162-4.) (56/35 Germany.)

On modern engine cylinders, fin spacings of the order of 2 mm. are not uncommon. Investigation of air flow inside these narrow gaps by means of the usual pitot tube is difficult. The hot wire anemometer is too fragile and its supports are liable to introduce considerable disturbances of the flow. The author describes a simple form of total pressure recorder, consisting of a copper tube 0.5 mm. outside and 0.3 mm. inside diameter, which is introduced facing the air stream. The static pressure is measured by means of a similar tube closed at the end and provided with an orifice on its upper surface. The experiments were carried out with a single engine cylinder (without piston and valves), the cowling being airtight at the cylinder base and head and projecting some distance beyond the cylinder confines. Air speed measurements were carried out over the central section facing the air stream and the integrated air flow agreed within 14 per cent. with the quantity entering the cowling from the blower. The air speed between the fins varied between 50 and 80 m./sec., the maximum speed occurring in the central gap on the head between the valves. The high value at this region is probably due to a venturi effect of the head passages. The air speed at the entrance section of the cowling was of the order of 10 m./sec., the total pressure being approximately 300 mm. of water. Power and flight experiments are in hand.

New Surfaces for Pistons. (E. Koch and P. Sommer, Year Book of German Aeronautical Research, Vol. II, 1937, pp. 193-197.) (56/36 Germany.)

Anodic treatment of aluminium pistons provides a hard skirt surface which was originally considered beneficial. The authors, however, describe experiments on aircraft engines which demonstrate that the anodised piston is distinctly inferior and will seize, even during the running-in period, although the clearances are

identical with those of the untreated piston. Only under conditions of repeated cold starting in the presence of excess fuel does the anodised piston show up to advantage. Although this may be of importance in the case of the motor car engines, this case is not likely to arise for aircraft engines. It is possible, however, that anodising the piston crown only is beneficial in reducing the effect of spark electrode sputter.

Much more promising than anodising appears to be a deposit of tin on the piston skirt. The authors describe how such deposits can be obtained electrolytically and satisfactory results have been obtained on motor car engines. Experiments with aero engine pistons are in progress. In this case the process is evidently limited by the working temperature of the piston skirt.

Cylinder Wear. (G. I. Finch, Autom. Eng., Vol. 28, No. 371, May, 1938, p. 166.) (56/37 Great Britain.)

It has been established that during the process of " running in," an amorphous " Beilby Layer " is formed, both on the piston and cylinder wall. The resultant smooth surface allows equalisation of oil pressure and prevents metal to metal contact. The fact that the cylinder wall wears more rapidly than the softer aluminium piston was formerly attributed to the lapping action of grit or dust which becomes embodied in the aluminium.

It has, however, been recently discovered that on prolonged running, the Beilby Layer on the aluminium piston (consisting originally of amorphous Al_2O_3) recrystallises into a form of sapphire which is responsible for the wear.

It appears possible that this harmful recrystallisation can be prevented by treating a suitable magnesium-aluminium alloy with a mixture of Al and Mg oxides. (Spinelising).

Engine trials with aluminium pistons treated in this manner are in progress.

Motion Pictures of Engine Flames Correlated with Pressure Cards. (G. M. Rassweiler and Lloyd Withrow, J.S.A.E., Vol. 42, No. 5, May, 1938, pp. 185-204.) (56/38 U.S.A.)

This paper represents a continuation of the work with the high-speed motion picture camera, described before the Semi-Annual Meeting of the Society, June, 1936.*

The experimental observations consist of pictures showing successive positions of the flame at intervals of 2.4 crankshaft deg. during single explosions, and pressure-time records of the same explosions.

A method, finally, is described for sorting out the pressure changes due to combustion from an observed pressure card. When the pressure changes resulting from combustion are summed, and put on a percentage basis, it is found that the percentage of pressure rise, due to combustion, is approximately equal to the percentage of charge burned (by weight) at the corresponding instants in the combustion period.

The Accessory Drive Problem of Aircraft Engines. (R. P. Lansing, J.S.A.E., Vol. 42, No. 5, May, 1938, pp. 205-8 and 224.) (56/39 U.S.A.)

A brief history of the subject is given, tracing the growth of accessory drives from their initial being as magneto drives down to the present stage, which embraces such items as automatic pilot pumps, de-icer compressors, and propeller governors. This review indicates that the present groups may well be divided into two parts; one, intimately associated with the operation of the

* See " Industrial and Engineering Chemistry," June, 1936, pp. 672—677: " High-Speed Motion Pictures of Engine Flames;" also S.A.E. Transactions. August, 1936, pp. 297—303: " Slow Motion Shows Knocking and Non-Knocking Explosions," both by Gerald M. Rassweiler and Lloyd Withrow.

engine, the other with that of the plane. The difficulties facing the engine designer, the installation engineer, and the operator, are outlined to illustrate the necessity of a new approach to this problem.

In view of the present general interest in auxiliary power plants, a short description of such an engine is included. The paper terminates by mentioning the present tendencies in the field and classifying the various means of accessory drive with the size of plane with which it, probably, will be employed.

Diesel Supercharging—the Effect on Design and Performance. (R. Pyles, J.S.A.E., Vol. 42, No. 5, May, 1938, p. 215.) (56/40 U.S.A.)

Methods of increasing engine output are discussed, and supercharging is said to involve few difficulties. The location of the blower drive as it affects frequency and gear loading is considered. Bearing-load diagrams are analysed for a high-speed and a low-speed engine.

Tests indicate a negligible increase in piston temperatures. Fuel consumption curves show fuel economy comparable with that of the normal engine.

Engine Installation and Related Problems in Large Aircraft. (I. L. Shogram, J.S.A.E., Vol. 42, No. 5, May, 1938, pp. 225-8.) (56/41 U.S.A.)

The author bases his arguments mainly on his experience with the Douglas D.C.4, a four-engined transport plane, 6,ooolb. gross weight, accommodating 42 passengers and a crew of five.

This aircraft is propelled by four P. & W. Twin Hornet engines fitted with Hamilton constant r.p.m. full feathering propellers (hydraulically operated). The author considers, in detail, the following features:—

Nacelles, Cockpit, Oil and Fuel System, Engine Controls, Exhaust System, Cowling and Induction System.

On the D.C.4, auxiliary engines are housed behind the main engine in the two inboard nacelles. These auxiliary engines each drive an 800 cycle 110 volt alternator as well as all air pumps and hydraulic units required either for the instruments or accessories. No batteries are installed.

It appears in these large machines the principal difficulty is the provision of simplified controls, bearing in mind, the complexity of the equipment.

The Effect of Air Passage Length on the Optimum Fin Spacing for Maximum Cooling. (M. J. Brevoort, N.A.C.A. Tech. Note No. 649, May, 1938.) (56/42 U.S.A.)

Consideration of fundamental knowledge, in part confirmed by the experimental evidence in this report, indicates that optimum fin spacing depends on the baffle length and the ratio of baffle length to fin spacing is approximately constant. With the proper choice of fin variables, as much heat can be dissipated from a short passage as from a long passage for a given pressure drop. Heat transfer can be improved by constructing the baffle so that the air flow is uniform throughout the fin space. The tests indicate that some improvement of cooling may be achieved by streamlining the cylinder and thus increasing the mass flow of air for a given pressure drop.

Further work in this field should be directed toward a more accurate and extensive knowledge of the detailed mechanism of the air cooling process on finned cylinders. With such knowledge as a basis, the problem of determining the optimum cooling arrangement of practical air-cooled cylinders, utilising all the factors within the designer's control, can be subjected to rational investigation.

A Photographic Study of Combustion and Knock in a Spark-Ignition Engine. (A. M. Rothrock and R. C. Spencer, N.A.C.A. Report No. 622, 1938.) (56/43 U.S.A.)

A photographic study of the combustion in a spark-ignition engine has been made, using both schlieren and flame photographs, taken at high rates of speed. Although shock waves are present after knock occurs, there was no evidence of any type of sonic or supersonic compression waves existing in the combustion gases prior to the occurrence of knock. Artificially induced shock waves in the engine did not themselves cause knock. The photographs also indicate that, although auto-ignition, ahead of the flame front, may occur in conjunction with knock, it is not necessary for the occurrence of knock. There is also evidence that the reaction is not completed in the flame front but continues for some time after the flame front has passed through the charge.

Laboratory Method for Determining the Behaviour of Lubricating Oils on Vaporisation. (H. Brückner, J. Soc. Chem. Ind. (Abstracts B), Vol. 57, No. 4, April, 1938, p. 344. Angew. Chem., 51, 1938, pp. 53-5.) (56/44 Germany.)

The sample is heated, under controlled conditions, up to 550° in a current of N_2 and the loss in weight recorded automatically. From the vaporisation-temp. curves are derived two empirical constants that serve to characterise the oils. Non-volatile residues are determined at the same time.

Engine Performance and Knock Rating of Fuels for High Output Engines. (A. M. Rothrock and A. E. Bierman, N.A.C.A. Tech. Note No. 647, April, 1938.) (56/45 U.S.A.)

Data are presented to show the effects of inlet-air pressure, inlet-air temperature, and compression ratio on the maximum permissible performance obtained on a single cylinder test engine with aircraft-engine fuels varying from a fuel of 87 octane number to one of 100 octane number plus 1 ml. of tetraethyl lead per gallon. The limiting factor for the increase in compression ratio and in inlet-air pressure was the occurrence of either audible or incipient knock. The data are correlated to show that, for any one fuel, there is a definite relationship between the limiting conditions of inlet-air temperature and density at any compression ratio. It is concluded that aircraft-engine fuels cannot be satisfactorily rated by any single factor, such as octane number, highest useful compression ratio, or allowable boost pressure. The fuels should be rated by a curve that expresses the limitations of the fuel over a variety of engine conditions.

Pressure Waves Accompanying Detonation in the Internal Combustion Engine. (C. S. Draper, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 219-25.) (56/46 U.S.A.)

The author's general experimental conclusion that the energy associated with pressure waves, due to detonation, is a small percentage of the total energy, agrees with the known result, that the output of a well-designed engine is not affected by moderate detonation intensities.

With the present data it is possible to calculate the maximum particle velocity at the cylinder wall due to the measured pressure waves.

Substituting values for the lowest frequency mode as given by the records, and remembering that the velocity normal to the cylinder wall must be zero, gives a maximum particle velocity of 50ft. per sec. While this figure does not represent a very high speed, the oscillatory motion will take place very close to the cylinder wall and possibly supply the " scrubbing action " suggested by Withrow and Rassweiler. The attendant high rate of heat transfer can well be responsible for the local pitting effects observed in the aluminium combustion chamber surfaces of certain engines.

As regards the selection of a unit of detonation intensity, suitable for all engines under all conditions, it seems reasonable to use the average pressure wave energy density. Thus, if an electromagnetic generator type of indicator is used, the associated electrical circuit should first integrate to reduce all frequencies to a common basis, then " rectify " and amplify, according to a square law with a final steady indication proportional to the rectified output.

Influence of Pressure on Film Viscosity in Heavily Loaded Bearings. (S. J. Needs, Trans. A.S.M.E., Vol. 60, No. 4, May, 1938, pp. 347-58.) (56/47 U.S.A.)

At constant speed and temperature, it has been observed that, when the load was increased to several thousand pounds per square inch the friction-coefficient curves for fitted journal bearings reached a minimum and then started to increase with added load. In the absence of metallic contact this discrepancy between observed and theoretical frictions suggested the probability of the high pressures in the bearing oil film causing an increase in film viscosity. The present paper undertakes a mathematical explanation of this phenomenon by calculating the effect of viscosity increase under pressure on the operating characteristics of plane surfaces of infinite width. Some of the more interesting of the test results are given in the form of curves and these are compared with calculations for plane surfaces of infinite width assumed to be operating under the same conditions.

Effect of Spark-Timing Regularity on the Knock Limitations of Engine Performance. (A. E. Bierman, N.A.C.A. Tech. Note No. 651, May, 1938.) (56/48 U.S.A.)

1. Irregular spark timing may appreciably reduce the non-knocking power range of an engine.

2. In the tests described, a change of one crankshaft degree in spark retard was equivalent to an 0.85 inch of Hg change in allowable inlet pressure.

3. Irregular spark timing may cause large errors in tests of the knocking properties of fuels.

4. Spark-timing errors can be determined with reasonable accuracy by causing the spark to puncture combined thicknesses of paper and cellophane tape attached to the engine flywheel.

Modern Welding Equipment. (Metropolitan Vickers Electrical Company, Vol. Tech. News Bulletin, No. 607, 22/4/38, p. 4. Electrical Engineer, 15/4/38, pp. 900-6.) (56/49 Great Britain.)

A brief survey is given of modern welding methods and equipment by various manufacturers. This includes descriptions of several types of d.c. and a.c. arc welding sets, an atomic hydrogen set, spot, butt and continuous spot and seam welders.

Illustrated with 20 photographs and two diagrams.

Torsion and Torsional Oscillations of Blades. (J. Duncan, Eng. Absts., Vol. 1, No. 3, Section 3, April, 1938, p. 22. Trans. of N.E.C. Inst. of E. and S., 31/3/38.) (56/50 Great Britain.)

The author gives methods of calculating the torsional rigidity of blades, and the natural frequencies of vibration, in terms of rigidity and mass, assuming a knowledge of the amount of the virtual fluid mass. Two methods of obtaining the rigidity, *i.e.*, the thickness-parameter method and the Galerkin method, are given, and detailed results worked out for certain sections. For a thin segment of a circle, and similar sections, the rigidity constant is approximately 16/105 (breadth) × (thickness)^3. An approximate method of calculating the natural

frequencies of the lower modes is given and the results compared with the exact solution for a uniform blade. In an appendix there is a note on airscrew flutter.

The Most Suitable Shape of Chamfered Corner for Crankshafts Subjected to Torsion. (H. Deutler and A. Havers, Yearbook of German Aeronautical Research, Vol. II, 1937, pp. 132-136.) (56/51 Germany.)

As is well known, a sudden change in diameter of a shaft produces a considerable stress peak at the corner. This can only be avoided if sufficient room is available for a gradual transition from the smaller to the larger diameter. In most cases the length over which the transition must take place is restricted and a certain stress peak is therefore unavoidable.

Using Foppl's Theory of Torsion as applied to shafts of variable cross-section, the author concludes that an elliptical transition curve is in most cases preferable to the circular chamfer commonly employed. If a and b are the semi-axes of the proposed ellipse

$$a/b = 1 + 2.5\ a/d$$

where a = major semi-axis of ellipse.
= length of chamfer.
b = minor axis of ellipse.
d = diameter of thin portion of shaft.

The main advantage of the elliptical transition curve is in the region

$$0.1 < a/d < 1.$$

The experiments of the authors indicate a maximum reduction of 10 per cent. in the stress peak and an increase in fatigue strength by a slightly smaller amount. If the length a is very restricted, it may be advisable to continue the chamfer into the corner in the form of a hollow groove.

Column Strength of Tubes Elastically Restrained Against Rotation at the Ends. (W. R. Osgood, N.A.C.A. Report No. 615, 1938.) (56/52 U.S.A.)

A study was made of the effects of known end restraint on commercially available round and streamline tubing of chromium-molybdenum steel, duralumin, stainless steel, and heat-treated chromium-molybdenum steel, and a more accurate method than any previously available was developed for designing compression members in riveted or welded structures, particularly aircraft.

The test specimens were centred under load on knife edges held in carriers, and the free lengths were computed by a rational method not heretofore used. Tensile and compressive tests were made on each piece of original tubing from which column specimens were cut. The column data were reduced with the aid of these tests, and formulæ were constructed to represent the column strengths in terms of specified tensile yield strengths of the four materials used.

The design is facilitated greatly by the use of tables and a nomographic chart, both included in this paper. A numerical example is also given.

Ball and Roller Bearings and Their Behaviour. (J. L. Brown, Metropolitan Vickers Tech. Bulletin No. 611, 20/5/38, p. 13. Elec. Journal, April, 1938, pp. 141-4.) (56/53 Great Britain.)

The inherent features and operating characteristics of the plain bearing and of ball and roller bearings are first discussed and compared. The author then proceeds to consider particular features of ball and roller bearings, *e.g.*, the need for a cage separator; troubles of misalignment; problems of lubrication; dangers of corrosion and the abrasive action of dust and dirt. Finally, the effects of high speeds on such bearings and on plain bearings are reconsidered. The article closes with some remarks on clearances and the S.A.E. figures of tolerance. Illustrated with one photograph and four diagrams.

Enamel Lacquered Wire. (J. Hoekstra, Metropolitan Vickers Tech. Bulletin No. 611, 20/5/38, p. 13 Philips Tech. Rev., Feb., 1938, pp. 40-7.) (56/54 Great Britain.)

The properties and applications of enamel lacquered wire are detailed. It is claimed that in addition to being unusually thin this form of insulation has a high breakdown potential, high electrical resistance, low moisture absorption, and good mechanical and chemical properties.

Illustrated with two photographs and four diagrams.

Corrosion Resistance Tests of Aluminium and its Alloys. (J. W. Smith, Metropolitan Vickers Tech. Bulletin No. 611, 20/5/38, p. 15. Light Metals Rev., May, 1938, pp. 124-5.) (56/55 Great Britain.)

It is stated that accelerated corrosion tests should be made both on the unprotected metal (with oxide film removed) and on the same material after its protective coatings have been applied. Standard methods of testing are described. The " oxygenated salt test " due to Mylius is then fully discussed. In this test the corrosion effect is measured in terms of loss in weight per unit area per day as well as decrease in mechanical properties. The " thermal " test of Mylius which employs hydrochloric acid instead of salt is described and precautions for testing tin sheets are pointed out. Finally, the limited validity of the test results is discussed with particular reference to heat treatment.

Heat-Resisting Steels. (W. H. Hatfield, Journal of the Institute of Fuel, Vol. 11, No. 58, April, 1938; Paper read before the Institute of Fuel, March 24th, 1938.) (56/56 Great Britain.)

An attempt has been made to evaluate on a quantitative experimental basis the different heat-resisting steels and alloys which are at the present time finding a progressively wider application. Whereas the time yield of mild steel falls to 400lb. per sq. in. at 700°C., it is shown that there are a number of steels available with a time yield of not less than 3,360lb. at that temperature, which clearly means that reasonably substantial stresses may be borne at a red heat with reasonable permanence of dimensions. It has been shown that such steels possess, along with the increased strength, resistance to oxidation on scaling to an astonishing degree.

Chromium alone, whilst giving resistance to oxidation, does not increase the strength of the steel. By adding substantial quantities of nickel to the chromium, the dual result is attained. It is shown also that the addition of tungsten is valuable in assisting in the attainment of higher strength.

From the economic point of view it is of considerable moment as to which and how much of the different elements are added, and therefore it is important that the engineer shall carefully consider the service required before selecting a given composition.

Polish on Metals. (W. Cochrane, Proc. Roy. Soc., Series A, Vol. 166, No. 925, 19/5/38, pp. 228-37.) (56/57 Great Britain.)

When electron diffraction patterns consisting of diffuse rings are obtained by Thomson's reflexion method, their interpretation is uncertain since such diffuseness may be caused by the geometrical configuration of the surface of the specimen. In order to eliminate this difficulty, a thin layer of gold was formed on a nickel base. The gold film was polished, then stripped off and examined by transmitted electrons incident normal to the film. The resulting pattern consisted of three diffuse rings. It was deduced that the film consisted of very small crystal grains and that the atoms in the polish layer of a metal are arranged similarly to the atoms in a monatomic close-packed liquid at a given instant. After a period of 15 hr. the polished gold film yielded a pattern of sharp rings

characteristic of polycrystalline gold, showing that crystal growth had taken place with a return to the normal crystal size.

Locomotive Axle Testing. (T. V. Buckwalter, O. J. Horger and W. C. Sanders, Trans. A.S.M.E., Vol. 60, No. 4, May, 1938, pp. 335-45.) (56/58 U.S.A.)

Rolled axles compared with unrolled axles show little improved resistance to the development of incipient fatigue cracks as produced by a large number of repetitions of low stresses obtained under ordinary railroad operating conditions of speed and load. Under prevailing conditions of high speeds and load, however, the occasional stresses are considerably increased and cause these incipient fatigue cracks to propagate and ultimately fracture the axle. Rolling provides immense increase in resistance to crack propagation, thus giving greater safety.

Maps for the Air Force. (B. V. Sterligov, Air Fleet News, U.S.S.R., Vol. 19, No. 9, Sept., 1937, pp. 7-15.) (56/59 U.S.S.R.)

1. The Air Force must have maps compiled on three different scales:—

Large scale (50,000)—for exact orientation in the zone of battle, in the vicinity of the objective and when co-operating with ground forces.
Medium scale (500,000)—for " mean " visual orientation in flight.
Small scale (1,500,000)—for general orientation, when choosing the course and when using compass, radio, or astronomical navigation.

2. Whereas the large scale maps (up to 200,000) should be edited mainly with a view to the needs of the ground forces, the medium and small scale maps (below 200,000) should be compiled with a main view to the information necessary for the Air Force.

3. The work and conditions of use of a map during flight necessitate an edition of the 500,000 and 1,500,000 maps greatly rationalised as regards the projection, contents, symbols, division into separate sheets and fastening together of the sheets.

4. Considerations of economising the maps and the time for preparing them for a flight make it necessary to publish them in two series with overlaps by half a sheet.

5. The introduction of a system of two maps (1,500,000 and 500,000) provide for all emergencies and any degree of detailed orientation, but it necessitates devising a new system of presentation of the 500,000 map by either cutting it into squares, or folding it into a " double concertina " which can be turned over in two directions.

6. Fighter pilots need a special map holder, which can be strapped to the pilot's knee.

Note on Approximations to Functions and the Solution of Differential Equations. (R. A. Frazer, W. P. Jones and S. W. Skan, Phil. Mag., Vol. 25, No. 170, pp. 740-6.) (56/60 Great Britain.)

The present brief paper gives some comparisons between three known methods of approximation, which will be referred to as (i) collocation, (ii) least squares, (iii) Galerkin's method. A fuller account, with numerical examples, is given in No. 1799 of the Reports and Memoranda of the Aeronautical Research Committee.

The term collocation is here used in connection with approximations to mean the act of assigning the error at one or more given points or stations.

The solution of differential equations by methods (ii) and (iii), which depend on the minimisation of average errors, has been considered by W. J. Duncan (R. and M. 1798). The original papers by V. G. Galerkin, describing method (iii), do not appear to be available in this country, but accounts with references are given in two papers by E. P. Grossman (Trans. C.A.H.I., Moscow, Nos. 186

and 253). Galerkin's method reduces to the method of least squares when it is applied to obtain approximate representations of functions.

The New 400-Degree Partition (of the Circle). (K. Herrmann, Eng. Absts., Vol. 1, No. 4, Section 1, April, 1938, p. 43. Zeit Vermessung, Vol. 47, 15/2/38, pp. 117-20.) (56/61 Germany.)

From 18th Nov., 1937, the 400° partition has been used exclusively for surveying in Germany. Formerly it was statutory only in the south, and Prussia continued to use the " old " (360 deg.) partition. The " new " system is advantageous in measurement, and particularly in calculation; but in order to secure the maximum advantage, both should be carried out in the " new " style. The saving of time is important, particularly in lower geodesy. Since calculation is decimal, no arc table is necessary. In actual use the case of conversion of degrees to superficial distances is important; since 1 m. $= 10^{-7}$ X (meridian quadrant of the earth), 1° (0.01 " new " degrees) = 1 km. distance. A similar relation holds between the sea-mile (1,852 m.) and 1 minute of arc. The author observes that in land surveying and higher geodesy it is already customary to express values in decimals of a degree and of a second respectively, this being a blend of both systems, so that no fundamentally new idea is involved. Disadvantages are the increased difficulty of conversion from astronomical to terrestrial units (1 hr. = 16.6 g against 1 hr. = 15 deg.), and the break in tradition.

Direct Determination of the Electrical Constants of Soil at Ultra-High Radio Frequency. (M. K. Chakravarty and S. R. Khastgir, Phil. Mag., Vol. 25, No. 170, 12/5/38, pp. 793-801.) (56/62 Great Britain.)

In the present investigation the attenuation of ultra-short waves travelling along a Lecher wire system immersed in a specimen of Dacca soil has been determined for a certain range of ultra-high frequencies (73 to 89 megacycles per sec.) and for varying moisture contents from 8 to 41 per cent. The values of the electrical conductivity and the dielectric constant of the soil are then determined by the application of the standard formulæ.

It is to be noted that the values of the electrical conductivity and the dielectric constant of the soil obtained by the direct laboratory method agree well in their orders of magnitude with the values estimated from the attenuation measurements.

Progressive Lightning. (B. F. J. Schonland, D. B. Hodges and H. Collens, Proc. Roy. Soc., Series A, Vol. 166, No. 924, 4/5/38, pp. 56-75.) (56/63 Great Britain.)

The photographic method of studying the lightning discharge by means of the Boys camera has the unique advantage of giving direct information concerning events in the discharge in two dimensions of space and one of time and could be extended if necessary to include the third space dimension. The luminous events which it records are, however, secondary processes, and the primary movements of electrical charge which cause them can only be inferred by an application of ideas gained from the laboratory study of the passage of electricity through gases.

The direct study of these primary electrical processes involves the observation of the electric field during the discharge by means of a cathode-ray oscillograph. The method gives information concerning the total electric moment of the cloud charges and requires to be compared with the photographic data before its results can be interpreted in terms of the charges themselves and their movements.

The present paper is concerned with field studies designed to correlate the information obtained by these two methods.

The Development of the Spark Discharge. (T. E. Allibone and J. M. Meek, Proc. Roy. Soc., Series A, Vol. 166, No. 924, 4/5/38, pp. 97-126.) (56/64 Great Britain.)

The electric spark is shown to consist of two principal components, a leader stroke and a main stroke—analogous to the lightning flash. A leader stroke generally starts from a positive electrode; sometimes the structure of the leader stroke is simple, sometimes it is of the " stepped " variety. The leader stroke is always branched at many places, and the direction of branching is the direction of its propagation in space; branching thus forms a criterion of the direction of leader stroke development. The main stroke develops in the reverse direction to that of the leader stroke and at a velocity too high to be recorded. The velocities of the positive and negative leader strokes are of the order of $10^6 = 10^7$ cm./sec. the positive leaders being the faster.

Special Maps for Use with Loop Direction Finders. (J. M. Coburn, J. Aeron. Sci., Vol. 5, No. 6, April, 1938, pp. 233-236.) (56/65 U.S.A.)

With the normal material, it takes 12 distinct operators to draw a wireless position line. With the simplification introduced by the author the number of operations is halved. The principal novelty is a loop bearing indicator, in which the calibration of the loop is already incorporated in the scale. The process of plotting is further simplified by providing a compass rose on the map round each radio range station. These roses are orientated on the magnetic north, the difference in magnetic variation at the position of the aircraft being neglected. The procedure for position finding is then as follows:—

(1) Radio tuned to desired station.
(2) Loop rotated to give minimum response.
(3) Bearing indicator read.
(4) This bearing added to compass reading.
(5) Deviation added or subtracted.
(6) Position line drawn.

Stability of Two-Metre Waves. (C. R. Burrows, A. Decino and L. E. Hunt, Proc. Inst. Rad. Eng., Vol. 26, No. 5, May, 1938, pp. 516-28.) (56/66 U.S.A.)

By continuously recording a signal of 150 megacycles over a 60-kilometre path for a year, fading of up to 20 decibels has been found. This instability was most pronounced from sunset to a few hours after sunrise. The average field strength also tended to be higher during the night. A comparison of stability over various paths from 60 to over 200 kilometres has revealed similar diurnal characteristics. For a shorter path of 30 kilometres, fading was found to be considerably less than for the 60-kilometre path.

The fading magnitude was found to be approximately the same on several 60-kilometre paths differing widely in attenuation and including both optical and non-optical paths.

Because of the nature of the variations over this 60-kilometre path an increase of 7 decibels in power would have been required to maintain the field equal to or greater than the observed mean value for 99 per cent. of the time.

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the Library of the Society.

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AERODYNAMICS.

478,512. *Improved Means for Stimulating the Air Flow Round an Aerofoil.* Garden, A. D., 58, Gloucester Terrace, Hyde Park, London, W.2. Dated July 17th, 1936. No. 19,832.

It is proposed to arrange that a portion or portions of an aeroplane are moved to form a wedge aerofoil, the latter being described as formed of two plates whose front edges are together and whose rear edges are separated. When exposed, the wedge aerofoil is above or below the wing in such fashion that it is wholly or in part overlapped by the wing.

479,598. *Improvements relating to the Reduction of Resistance of Bodies Moving in Fluids.* Miles, F. G., Reading Aerodrome, Woodley, Berkshire. Dated July 6th, 1936, No. 18,777, and Aug. 6th, 1936, No. 21,704.

It is proposed to suck away the boundary layer on an aeroplane surface through ducts connected to air sucking means, the area concerned being perforated nearly uniformly so that the surface is porous. The air sucked is preferably exhausted over the top of the rear portion of the fuselage. The ducts have various throttling devices to localise and control the abstraction as may be found desirable.

477,894. *Improvement in Lifting Means for Aircraft.* Master, S. D., 24, Churchgate Street, Fort, Bombay, India. Dated July 7th, 1936. No. 18,840.

It is proposed to produce a vertical lift aircraft of small overall size by using a lifting device consisting of wings or vanes arranged to form a hollow truncated cone or a square or polygonal pyramid. The latter provides a housing for one or more propellers, the latter being so arranged that air is forced into the wings and also through the top opening of the housing. It is claimed that an upward lift results.

AIRCRAFT—CONSTRUCTION.

478,089. *Improvements in the Construction of Aircraft Wings.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated July 7th, 1936. No. 498.

In the proposed wing there is an upper portion consisting of the skin and upper part ribs and a lower portion with lower portion ribs without webs or shear bracing. These are combined to form the wing. In each section there is a boom located at the deepest portion, the boom being attached to the skin and to the part ribs. The booms take the horizontal component of the bending moments, the part ribs receiving the loads from the skin.

478,307. *Improvements in and relating to Fuselage, Body or Hulls of Aircraft.* Martin, J., Higher Denham, nr. Uxbridge, Middlesex. Dated July 13th, 1936. No. 19,448.

The bodies of aircraft are formed by channel section strips which are assembled in sets each consisting of a number of the joined channel section strips. The sets are connected together by bolting, riveting, or welding. The strips are curved or tapered to conform to the body with their flanges turned inward and are fastened together. Bulkheads are provided at suitable intervals.

477,541. *Improvements in or relating to the Construction of Wings and other Aircraft Bodies or Parts.* The Supermarine Aviation Works (Vickers), Ltd., and Mitchell, R. J., both of Woolston, Southampton, Hampshire. Dated July 2nd, 1936. No. 18,353.

In order to avoid the expensive riveting of the sheet metal covering of the wings, it is proposed to attach these sheets by means of wood screws. The plates may be joggled at their junctions in such a manner as to form an external recess above the junction. The wooden member is multiply forming part of the interior structure, and a strip member is provided which fits into the exterior recess. The wood screws are countersunk.

481,050. *New or Improved Means for Folding Monoplane Wings.* Short Bros. (Rochester and Bedford), Ltd., and McVie, R., both of Seaplane Works, Rochester, Kent. Dated March 18th, 1937. No. 7,961.

The proposed wing has a stub portion, the rear part of which folds forwards. The folding portion is first folded back into a fore and aft position and afterwards turned so as to tip up the wing. The folding wing is locked by fore and aft fasteners which support the wing when spread. These fasteners can be retracted for folding the wing. There is a hingeing extension for supporting the wing when the fasteners are unlocked.

481,058. *A New or Improved Method of Covering Aircraft Wing Surfaces and Bodies.* Short Bros. (Rochester and Bedford), Ltd., and Shepherd, P., both of Seaplane Works, Rochester, Kent. Dated April 16th, 1937. No. 10,889.

This arrangement specially applies to cases of wings where the leading portion is covered with metal, and the rear of fabric. The rear of the metal skin is joggled inwards and has thread holes, while a clamping member is provided pressing against the joggled part and having thread holes corresponding with those in the rear of the skin. The leading edge of the fabric is lapped round the clamping member and attached by stitching.

480,685. *Improvements in Thin Sheet Covered Aircraft Bodies, Wings and the Like.* A.T.S. Co., Ltd., 3/4, Clement's Inn, Strand, London, W.C.2, and North, J. D., Hill House, Eaton, Norwich, Norfolk. Dated Aug. 20th, 1936. No. 22,965.

It is proposed to attach straight lengths of stringers to the covering sheets when these are flat along selected lines which remain straight when the covering sheets are curved to their final form. Units thus formed may be attached to frame pieces which lie transversely to the stringers at intervals and impose the correct curvature on the covering. Two or three such units may be assembled to form a fuselage or wing.

479,532. *Improved Joint for a Folding Strut, Arm, or the Like.* Thornhill, P. W., 32, Heath Terrace, Leamington Spa, Warwickshire; and Onions, J. H., 18, Telford Avenue, Leamington Spa, Warwickshire. Dated Aug. 21st, 1936. No. 23,010.

This specification describes a retractable aircraft chassis. In order that the wheel shall be horizontal after retraction, when the chassis is retracted rearwards, the two mounting axes of the main strut carrying the landing wheel are both inclined to the planes containing respectively the longitudinal and normal axes and the lateral and normal axes. One of the axes is also inclined to the plane containing the longitudinal and lateral axes. The effect is that the strut is turned during retraction so that the wheel is finally horizontal so that it can be retracted into a wing.

479,839. *Improvements relating to the Construction of Aircraft Structures or Components Thereof.* Greig, L. T. H., Granada, Mount Felard, Millbrook, Jersey. Dated July 8th, 1936. No. 18,964.

It is proposed to construct aircraft components, such as wings, fuselages, etc., by winding tensile reinforcement material into the desired form of the component, *e.g.*, to form a lattice of wire or metal ribbon and also to wind strip material into the same form so as to form a virtually continuous skin, the whole being impregnated with a form of cement which can be hardened.

478,855. *Improved Means for Securing Fabric to Aircraft Wings and the Like.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Bray, F. C., Borray, 248, Great West Road, Hounslow West, Middlesex; Budd, O. J., 1, Grangewood Villas, Grange Road, Hayes, Middlesex; and Roberts, H. F., 21, Glebe Road, Hayes, Middlesex.

The top flange of the wing rib is of U section and it is transversed at intervals by eyelets, rivets, or the like, and the cord which is laid over the fabric is threaded to and fro through the latter and round under the eyelets, enabling the fabric to be pulled down partially into the rib U.

482,166. *Aeroplane Wing Structure.* Barkley, A. St. C., 318, Grand Boulevard, Detroit, Michegan, U.S.A. Dated Feb. 16th, 1937. No. 4,514.

The proposed wing has a multiple wing structure having a pair of longitudinal segments of fluted sheet metal which form a series of closed circular or polygonal passages extending along the length of the wing. Each passage is rigidly connected to the stressed skin of the wing. Fluted segments extend from the leading to the trailing edges of the wing between vertical spars.

482,782. *Improvements in the Construction of Wings for Aircraft.* Brodeau, A. H. J., 4, Villa Ornam, Paris, XVIII, France. Convention date (France), April 9th, 1936.

It is proposed to construct aeroplane wings of a sheet of material shaped to the wing camber and composed of agglomerated cork stuck between two layers of wood so that the wing is hollow. Balsa wood, sponge, ebonite, etc., may be used in place of the cork.

480,210. *Improvements in the Construction of Aeroplanes.* Renault, L., 8, Avenue Emile Zola, Billancourt (Seine), France. Convention date (France), Feb. 14th, 1936.

It is proposed to use a resilient assemblage between adjacent parts of an aeroplane. It is stated that this arrangement has the effect of reducing stresses and also of stopping vibration. These resilient connections may be made of rubber sleeves or less easily deformable rubber blocks.

480,221. *Improvements in or relating to Aircraft Structures.* Mercier, P. E., 9, rue Marbeau, Paris, France. Convention dates (France), April 29th, 1936, and Aug. 12th, 1936.

It is proposed to construct box spars for aeroplane wings by arranging on the periphery a number of partitions or frames arranged substantially parallel, longitudinal elements of wood in juxtaposition to each other, preferably glued together. The elements are approximately at right angles to the partitions, the whole assembly being bound together with hoops in a similar way to the hoops of a barrel.

480,269. *An Improved Self-Supporting Wing or Control Surface for Aircraft.* A.T.S. Co., Ltd., 3/4, Clement's Inn, Strand, London, W.C.2, and North, J. D., Hill House, Eaton, Norwich, Norfolk. Dated Aug. 20th, 1936. No. 22,938.

The proposed wing comprises a pair of main spars and sheet covering adapted to resist shear. The top and bottom covering extends between the spars over the length of the outer portion thus constituting a tubular member, and the covering is wholly or in part detachable between the spars over the length of the inner part where it extends round the nose and the tail constituting two tubular members, one with each spar. A strong rib at the juncture of the outer and inner wing portions receives the torque from the outer portion and conveys it to, and distributes it over, the two tubular members which constitute the inner portion.

480,273. *Improvements in Aeroplane Spars and other Members.* A.T.S. Co., Ltd., 3-4, Clement's Inn, Strand, London, W.C.2, and North, J. D., Hill House, Eaton, Norwich, Norfolk. Dated Aug. 20th, 1936. No. 22,966.

A corrugated web is secured to only one surface of a boom by riveting, welding, etc., directly through those surfaces of the corrugations which lie in contact with that surface of the boom, and the web is stiffened to resist shear by one or more stiff members secured to it across the corrugations and along lines extending between the booms.

482,488. *Monospar Cantilever Aircraft Wing.* Klemm, H., Waldburgstrasse 29, Boblingen, Germany. Convention date (Germany), June 26th, 1936.

It is proposed to use a hollow spar of elliptical or aerofoil shape forming the foremost portion of an aeroplane wing. The spar has a longitudinal stay plate near the point of widest cross section of the wing, and transverse members extending therefrom to the leading edge. The trailing portion of the wing is formed by part ribs with an ordinary covering.

AIRCRAFT—GENERAL.

477,238. *Improvements in Aeroplanes.* Pollopas Patents, Ltd., 2 and 3, Charterhouse Square, London, E.C.1. Convention date (Germany), Feb. 19th, 1936.

It is proposed that an aeroplane as claimed in Specification 459,639 wherein the support or the upper portion thereof is pivotally mounted in such manner that the said support or the said upper portion may be inclined backwards, forwards or sideways. The upper portion of the support may also be telescoped up and down. The upper portion may be lowered so that it rests on one of the supporting surfaces or on the fuselage. Vertical planes are attached to the tips of the wings.

AIRSCREWS.

481,014. *Improvements in or relating to Wind or Water Wheels for Use as Prime Movers, Propellers or as Sustaining Devices for Aircraft.* Daniel, P. G. L., 31, rue du Commandant Reviere, Colombes, Seine, France. Convention date (France), Sept. 7th, 1935.

The wheels proposed have vanes which have a rotational movement relative to the wheel and in a direction opposite to that of the wheel. Each vane is formed by a rigid framework having attached a sheet of elastic material so that the sheet curves under the action of the fluid.

BOMBS AND BALLISTICS.

481,931. *Improvements in Ammunition Boxes or Holders.* Rethel, W., Grabenstrasse 10, Brandenburg (Havel), Germany, and Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung, Brandenburg (Havel), Germany. Dated Nov. 17th, 1937. No. 31,595.

This is an ammunition box holder for use in aircraft wings characterised by this, that the box-shaped ammunition holder is composed of several individual boxes arranged in series forming a communicating chamber, which consists only of a bottom, two longitudinal side walls, the bottom of the individual boxes at their neighbouring edges being connected by hinges in such manner with one another that the individual boxes can turn about the said edges.

CATAPULTS.

478,427. *Improvements in and relating to Devices for Accelerating Aircraft for Launching Purposes.* Mitchell, C. C., 26, Chermiston Road, Corstorphine, Edinburgh 12. Dated May 18th, 1936. No. 14,074.

The device proposed is a type of catapult having a slotted cylinder carrying a piston behind which pressure can be generated. Connected to the piston and projecting from the cylinder is a fitting which works in the slot. The slot can be closed to pressure by means of an endless belt, inside the cylinder, carried by a pulley on the piston. Fluid under pressure may be admitted to the reverse side of the piston for braking purposes.

480,692. *Improvements in and relating to Apparatus for Accelerating Aircraft for Launching Purposes.* Mitchell, C. C., 26, Chermiston Road, Corstorphine, Edinburgh 12, Scotland. Dated Aug. 25th, 1936, No. 23,305, and Feb. 25th, 1937, No. 5,660.

The catapult proposed has a cylinder containing a piston, which latter is attached to a cord with a smooth exterior which is attached in its turn to the carriage holding the aircraft. The smooth cord passes through a gland and passes over pulleys. A by-pass arrangement is provided so that the carriage may be decelerated at the end of the run.

482,160. *A Method and Means for Launching and Landing Aircraft.* Plesman, A. Hofweg, 9, The Hague, The Netherlands. Convention date (Holland), Jan. 21st, 1936.

It is proposed to employ aircraft without means of enabling an independent

landing to be made, *i.e.*, without a chassis or floats. The aircraft when getting off or landing is supported by one or more auxiliary aircraft carrying the landing gear. Such aircraft may be launched by catapult and at the end of the journey can be caught by the auxiliary aircraft. These auxiliary aircraft are adapted to be coupled or uncoupled to the main aircraft during flight.

482,057. *Improvements relating to the Take-off of Aircraft.* Sir W. G. Armstrong Whitworth Aircraft, Ltd., and Lloyd, J., both of Whitley, Coventry. Dated Nov. 24th, 1936. No. 32,122.

It is proposed to accelerate the take-off of an aircraft by mounting it on a motor-driven truck of which the power/weight ratio is not less than that of the aircraft starting and accelerating the truck as quickly as possible while operating the aircraft engines, up to a speed at which the aircraft is air-borne, then releasing the aircraft and stopping the truck.

CONTROL OF AIRCRAFT.

478,190. *Improvements in and relating to Aircraft Wings.* Garden, A. D., 58, Gloucester Terrace, Hyde Park, London, W.2. Dated June 9th, 1936. No. 16,087.

The wing is fitted with a split flap and when this is lowered a rearwardly opening slot in the wing is uncovered. This slot communicates from the upper surfaces of the wing to the wedge-shaped cavity between the flap and the trailing edge.

477,395. *Improvements in Stabilising Devices for Aeroplanes.* Billioque, E. J. H., 39, Avenue du Belvedere, Le Pre Saint Gervais (Seine), France. Convention dates (France), May 24th, 1935, and March 3rd, 1936.

The aeroplane has a plane pivoted in front of its centre of pressure on an axle parallel to the pitching axis, the size being adjusted that it balances the effort produced by the resistance at the rear of the fuselage. The plane is normally allowed to float, but becomes operative and contacts with a stop when the nose of the aeroplane drops as the result of a stall. The device is only intended to play an active part below the stalling speed.

477,506. *A Device for Limiting the Aerodynamic Efforts on Aircraft.* Mercier, P. E., 9, rue Marbeau, Paris, France. Convention dates (France), April 10th, 1936; June 13th, 1936; Feb. 18th, 1937.

It is proposed to limit automatically the aerodynamic efforts ensuring the support of aircraft by control of the deflection of a flap with or without a slot. There is a combination of a flap, of a servo motor for operating the flap, of a member controlling the operating gear of the servo motor, the positions of which are a function of the deflection of the flap and the deformation of the wing caused by aerodynamical forces.

482,080. *Improvements in or relating to Aircraft Control Systems.* Mercier, P. E., 79, Boulevard Haussmann, Paris, France. Convention dates (France), June 11th, 1936, and June 18th, 1936.

It is proposed to use a form of aircraft control comprising the combination of movable fins or fins with flaps, mounted perpendicularly and arranged at the centre of gravity, and of vertical tail surfaces which are also movable or which are provided with flaps. It is stated that with this combination it is possible to turn an aeroplane without banking.

477,844. *Safety Means for Use in Preventing or Correcting Spinning in Aircraft.* Martin, J., Martin's Aircraft Works, Higher Denham, Uxbridge, Middlesex. Dated July 4th, 1936. No. 18,618.

In order to stop a spin when it has occurred it is proposed to fit flaps above the

fuselage and just in front of the tail unit, the flaps being on the top of the fuselage and pivoted longitudinally. When not in use they fold flush into the fuselage, but when opened they are claimed to divert air on to the rudder when the aeroplane is at a high angle of incidence.

CONTROLS.

477,194. *An Improved Arrangement for Locking the Control Surfaces of a Parked Flying Machine.* Junkers Flugzeug-und Moteurwerke, Aktiengesellschaft, 39, Junkerstrasse, Dessau, Anbolt, Germany. Convention date (Germany), Feb. 29th, 1936.

There is a brake provided to act on the control surface to be locked, or on a member adjacent thereto and connected therewith by rigid levers or links, the brake being arranged to lock the surface and being connected with a brake control member in the cockpit.

480,674. *Improvements relating to the Control of Fluid-Operating Systems Particularly for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated June 27th, 1936, No. 17,905; Aug. 14th, 1936, No. 22,453; Aug. 14th, 1936, No. 22,454; and Feb. 3rd, 1937, No. 3,232.

A hydraulic control system is proposed in which a continuously operating pressure circuit may be diverted to operate any one of a number of receivers selectively. The receivers may be double acting. There is provided a selector unit which can be operated to divert the entire flow to a receiver and a separate cut-out valve diverting flow from the main circuit to the valve unit only when selective control has been exercised. The selector unit comprises a number of spring-loaded non-return valves with mechanical operating means.

480,687. *Improvements relating to Fluid Pressure Flap-Operating Devices for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucester. Dated Aug. 22nd, 1936. No. 23,159.

In the case of flaps operated from an engine driven pump, it is desired that the speed of operation may be high when the engine is idling and that the speed may be slow when the engine is running at high speed. A pressure fluid accumulator is provided which receives pressure fluid against resilient resistance and is arranged in parallel with the jack. This device forms a buffer which allows fluid pressure to be relieved when the engine is running fast. The resilient means may be compressed air or a spring.

477,817. *Improvements in Damping Joints for Control Surfaces of Aircraft.* Etablissements D.F., 188, rue d'Alesia, Paris, France. Convention date (France), July 28th, 1936.

In order to prevent flutter it is proposed to damp the movement of aircraft controls by means of a hydraulic damping device of the oscillating vane type which is arranged between the control surface and the fixed surface, the axis being coincident with the main hinge pin, the latter being connected with the pivot pin of the device. The pivot pin and the damping device may be combined.

480,180. *Improvements in or relating to Control Valves.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1, and Church, E. C. S., Beechcroft, Kenilworth Road, Leamington Spa, Warwickshire. Dated Aug. 20th, 1936. No. 22,959.

This specification refers to control valves for liquid pressure control systems. A control valve for such a system consists of a single pressure creating unit which actuates a number of controlling elements comprising a separately operable valve

plunger controlling the supply of pressure liquid in one or more directions to each controlled element. A valve plunger which has been moved is returned automatically when the movement of the controlled element is completed. The plungers are returned by pressure acting on annular forces on the plungers and the latter are retained in position by locking mechanism.

482,404. *Improvements in or relating to Mechanical Remote Control Apparatus.* Exactor Control Co., Ltd., Exactor Works, Mount Pleasant, Alperton, Middlesex, and Parker, W. H., of the same address. Dated March 13th, 1937. No. 7,440.

A remote control system has a mechanical bond such as a cable between two stations connecting movable elements and spring means at each station for keeping the bond in tension. There is means for keeping the spring effort of one station nearly equal to that of the other.

ENGINES.

480,345. *Improvements in Cowlings for Aircraft Engines.* Birkigt, L., rue de Capitaine Guynemer, Bois-Colombes (Seine), France. Convention date (Belgium), Feb. 12th, 1936.

The cowling described is, in general appearance, similar to the normal cowling used with air-cooled radial engines, but, internally, the space behind the front aperture is shaped to form a radial diffuser, the cross-section areas of which are inversely proportionate to the middle diameters. The crankcase of the engine may have a cone-shaped member in front, and various methods are described for the purpose of improving cooling, etc.

480,478. *Improvements in or relating to a Pneumatic or Hydro-Pneumatic Device for the Remote Control of Movable Vanes for Use in Regulating the Flow of Air through a Slot or Orifice.* Etablissements Livre et Olivier, 66, rue Boissiere, Paris, France. Convention dates (France), Jan. 6th, 1936, and Nov. 14th, 1936.

It is proposed to operate the vanes which control the size of the aperture behind an engine cowling, by means of a fluid under pressure. Each vane has a projection which rests on a flexible chamber shaped somewhat like a pneumatic tyre, the vanes being operated when pressure is introduced into the chamber. The vanes are returned by means of springs. Compressed air or liquid may be used to operate the device.

478,909. *Mountings for Engines, Especially on Aircraft.* Getefo Gesellschaft fur Technischen Fortschritt mit beschrankter Haftung, 13, Wayrsch-strasse, Berlin, W.35, Germany. Convention date (Germany), Jan. 25th, 1936.

It is proposed to construct a mounting by arranging a bearing of resilient material such as rubber round the longitudinal axis of oscillation so that the rubber is solely subjected to shearing stresses. The resilient bearings are arranged round the engine on mounting rings possessing an axis which is co-axial with the axis passing through the centre of gravity of the system and parallel to the engine crankshaft. The rings are perpendicular and placed on each side of the centre of gravity.

478,935. *Improvements in or relating to Cowlings for Aircraft Engines.* Mercier, P. E., 9, rue Marbeau, Paris, France. Convention dates (France), Dec. 23rd, 1936, and Feb. 5th, 1937.

This cowling is intended for radial engines and has two concentric passages, one within the other. The cooling air flows into the inner passage, passes over the engine cylinders and is then turned back through the outer passage and is

finally discharged to the atmosphere. The concentric passages are annular, and the inner passage adjacent to the inlet diverges in the direction of the airflow while the outer conduit converges in the direction of the airflow. The heated air is discharged through an adjustable slot near the nose of the cowling.

479,822. *Improvements in and relating to Driving Machinery for Aeroplanes.* Allmanna, Svenska, Electrischa Aktiebolaget Vasteras, Sweden. Convention date (Sweden), May 29th, 1936.

It is proposed to use the energy of the exhaust gas of a motor in a turbine which, in addition to driving a supercharger, also drives an auxiliary propeller. The engine drives a normal propeller through a reduction gear and, fitted concentrically, there is a smaller propeller driven by a radial flow turbine actuated by the exhaust gas. The shaft from the other side of the turbine drives the supercharger.

479,826. *Improvements in and relating to Aircraft.* The British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. Convention date (U.S.A.), June 26th, 1936.

It is proposed to use a single supercharger for supercharging an engine and also a passenger cabin for use at high altitudes. The compartment to be supercharged and the engine are connected in series, so that the air supplied to the compartment is warmed by compression and that the compartment is ventilated and the air is cooled before reaching the engine. Multi-stage supercharging may be used and there may also be an exhaust heated device for warming the air supplied to the compartment or a device for cooling it.

478,830. *Improvements in or relating to Aircraft.* Westland Aircraft, Ltd., Yeovil, Somerset, and Petter, W. E. W., of the Company's address. Dated Sept. 18th, 1936. No. 25,390.

In engine layouts where the engine is disposed within the aeroplane wing it is stated to be desirable that the engine shaft shall lie forward of the main wing spar. It is proposed that the engine crankcase shall conform substantially with the nose of the wing, and that the cylinders shall extend rearwards, the engine being of a V-type. The engine is mounted at each end upon brackets which connect with the main wing spar.

478,752. *Improvements in or relating to the Mounting of Aircraft Engines.* Getefo Gesellschaft fur Technischen Fortschritt mit Beschrankter Haftung, 13, Wayrschstrasse, Berlin, W.35, Germany. Convention date (Germany), Sept. 28th, 1935.

In order to take the engine mounting loads produced when an aeroplane is diverted from a dive into an ascent it is proposed that this strain is taken by rubber in compression. In a radial engine rubber blocks are mounted at intervals round the periphery of the engine casing which support the engine radially and other rubber blocks between axially opposed surfaces of engine members and frame members. These axially placed rubber blocks resist the forces produced on the engine mounting by the manœuvre described above.

482,135. *Improvements relating to Aeroplane Wings.* The Bristol Aeroplane Co., Ltd., Fedden, A. H. R., and Owner, F. M., all of Filton House, Bristol, Gloucestershire, and Copley, J. W., 44, Norton Road, Bristol, Gloucestershire. Dated May 4th, 1937. No. 25,962.

This specification is concerned with aircraft having the engines buried in the wings, and refers to an engine with horizontally disposed cylinders having the crankshaft axis fore and aft, supported near the middle of its length by a front frame, and at the rear by a rear frame, the frame forming part of the wing spars. The proposed engine is air-cooled, and ducts are formed in the wing for conveying cooling air. Part of the wing bracing may be formed by the engine crankcase.

482,151. *Improvements in the Installation of Supercharged Internal-Combustion Engines in Aircraft Structures.* The Bristol Aeroplane Co., Ltd., Fedden, A. H. R., and Owner, F. M., all of Filton House, Bristol, Gloucestershire. Dated Nov. 2nd, 1936. No. 29,806.

This specification is concerned with supercharged aircraft engines in which the air is cooled after supercharging. It is proposed to house the cooler within the aircraft wing and to use intakes which supply air both to the cooler and to the supercharger. There may be branched pipes, one branch of each leading to the supercharger and the other to the cooler. The supercharger may be driven directly or by an exhaust turbine, and an oil cooler may be incorporated in the installation.

481,394. *Improvements in or relating to Engines arranged to Accommodate Co-axially Disposed Firearms.* Gadoux, E. M., 16, Quai de Seine La Frette (Seine-et-Oise), France, and Crousse, L., 6, rue Rougemont, Paris, France. Convention date (France), Jan. 12th, 1937.

The main axis of the proposed engine about which transmission is effected is free of parts so that it can accommodate a gun barrel. Separate motor units are disposed about the main axis on radial shafts. These drive a hollow central shaft by gearing. Alternatively an arrangement is suggested in which two co-axial propellers may be driven in opposite directions.

483,055. *Improvements in and connected with the Cowling and Air-Intakes for Power Units of Aircraft.* Martin, J., Higher Denham, near Uxbridge, Middlesex. Dated Oct. 9th, 1936. No. 27,480.

The cowling proposed is intended for air-cooled engines. It has openings in front, some of which collect the cooling air while others collect the air for the carburettors, so that the air for each is kept completely separate. A separate opening may be made through which air can be supplied to an oil-cooler.

477,627. *Aircraft Cowling.* Read, J. R., High Gable, Sutton Avenue, Challaston, nr. Derby, England. Dated Aug. 7th, 1935. No. 21,811.

This cowling has parts for the admission of cooling air and the flow of air may be regulated by a number of shutters controlling the discharge orifice. The shutters swing about individual fulcrums so that their rear edges are moved away from or towards the remainder of the cowling. Each shutter overlaps so that there are no gaps between the shutters.

481,986. *Improvements in or relating to the Actuation of Suction-driven or Pressure-driven Apparatus by Internal Combustion Engines.* de Havilland, H., and the de Havilland Aircraft Co., Ltd., both of Hatfield Aerodrome, Hatfield, Hertfordshire.

It is proposed to use the combination of pressure-actuated auxiliary apparatus for the aircraft and conduits connecting the apparatus with a Venturi system associated with the engine exhaust. It is also proposed to combine the pressure actuating apparatus and conduits connecting the apparatus to at least two pressure points of the engine, the said points being selected so that the pressures are complementary to each other.

INSTRUMENTS.

478,094. *Improvements in Methods and Apparatus for the Distant Recording and Indications of Displacements or Deformations and Their Applications.* Mercier, J., 131, Boulevard de la Seine, Neuilly-sur-Seine, France. Dated Feb. 26th, 1937. No. 5,792.

The deformations are transmitted to the indicating means by way of an elastic transmission. The transmission is to be rendered practically rigid by eliminating the elastic device or by rendering it rigid at the moment when the deformation

has to be indicated with great precision. The device is said to be suitable for retractable undercarriages.

480,849. *Improvements in or relating to Instrument Boards for Aircraft.* Shevlin, J. T., 15, South Street, London, E.C.2. Dated July 28th, 1937. No. 20,931.

It is proposed that each measuring instrument should comprise four measuring mechanisms which are so arranged upon the board that the mechanisms referring to the same driving mechanisms are located one under the other vertically, so that the measuring mechanism groups are arranged side by side in a corresponding manner to the driving mechanisms, and the mechanisms which register corresponding features of the driving mechanisms are arranged horizontally. Under zero conditions the pointers are horizontal.

KITES.

481,617. *A New or Improved Kite.* Arthur, J., 18, Gardener's Crescent, Edinburgh, 3. Dated Oct. 22nd, 1936. No. 28,696.

The proposed kite has a main kite surface, stretching members for stretching said kite surface, a tail section attached at its forward portion to the posterior portion of the main kite surface and an ancillary body section superimposed upon the central portion of the main kite surface and so attached to the front of the kite surface and to the tail surface in rear of the attachment of the latter to the main kite surface that air currents can flow under and distend the ancillary body section when the kite is in flight.

MISCELLANEOUS.

481,375. *Improvements in and relating to Apparatus for Training Aviators.* Link, E. A., 10, Avon Road, City of Binghampton, New York, U.S.A. Dated Sept. 19th, 1936. No. 25,528.

The apparatus proposed consists of a dummy aircraft mounted on and manœuvrable relatively to a support by means of dummy aircraft controls. Indicating instruments are provided which are co-ordinated with the machine and which indicate in the same manner as on a real aeroplane. A compass which simulates the action of a real compass when the aeroplane is turned or banked is provided. Instruments simulating an air speed indicator, a climb indicator and an altimeter are provided, which are arranged to act as they would in a real aeroplane.

MODEL AIRCRAFT.

483,018. *Improvements in or connected with Model Aeroplanes.* Back, W. E., Mancroft Towers, Oulton Board, Suffolk. Dated Oct. 9th, 1936, No. 27,417; Oct. 23rd, 1936, No. 28,835; and Dec. 8th, 1938, No. 33,658.

This is a proposal for a toy aeroplane or glider in which the plane is attached elastically to the fuselage so that under the influence of a lifting force greater than the weight of the machine the wing will move so as to reduce the angle of incidence. The wing can swivel if the aeroplane strikes an obstacle, and the tail plane is arranged in the same way. There are also claims regarding the construction.

PARACHUTES.

478,384. *Improvements in Parachutes.* Sedlmayr, G., Berlinerstrasse 167/168, Berlin-Temple-Hof., Germany. Convention date (Germany), Sept. 16th, 1935.

It is proposed to avoid the danger of the parachute rupturing owing to eccentric opening shocks, by arranging that the canopy of the parachute shall yield to the

shock. The proposed canopy has an air vent and the shroud lines run from one side to the other over the apex. All or certain of the shroud lines fastened on both sides only at the lower skirt of the canopy are differently connected to the skirt of the air vent in the canopy, so that the parachute canopy can be displaced within certain limits on the carrier forward by the suspension lines.

478,476. *Improvements in or relating to Parachutes.* Capel, W. J. M., 18, rue d'Alsace, Toulouse, Haute-Garonne, France. Convention date (France), May 1st, 1936.

It is proposed to use liquefied carbon dioxide gas to cause the opening of a parachute. In order to do this the gas may be discharged into a chamber or sleeves attached to the canopy.

482,316. *Improvement in Method of Closure of Parachute Packs.* Caspar, F. A., Pak Parachute Co., Ltd., 175a, Streatham Road, Mitcham, Surrey. Dated Oct. 30th, 1936. No. 29,491.

The proposed pack has dual releasing means, a fastening device for a releasable flap consisting of a tab with a widened terminal portion held by a pair of studs held by a spacing member to which latter the studs are fastened by the two releasing means. Operation of either means allows the tab to be freed.

481,455. *Improvement in Method of Folding Parachutes.* Caspar, F. A., and Pak Parachute Co., Ltd., both of 175a, Streatham Road, Mitcham, Surrey. Dated Dec. 5th, 1936. No. 33,382.

The method of folding proposed consists in doubling back the peripheral margin of the canopy before folding the gores upon one another, so that the tension in the rigging lines when the parachute is released serves to pull forward the doubled back portion and thus provide an open mouth into which the air readily enters.

REFUELLING.

480,276. *Improvements in Apparatus for Refuelling Aircraft in the Air.* Sir Alan Cobham, K.B.E., Ford Aerodrome, Yapton, Sussex, and Flight Refuelling Co., Ltd., 8, Sergeant's Inn, Temple, London, E.C.4. Dated Aug. 21st, 1936. No. 23,021.

It has been proposed to weight the connection cord with a bag containing liquid so as to prevent damage to an aircraft picking up the bag. It is now proposed to substitute a balloon containing sufficient of a granular solid to weight it, the remainder of the balloon being filled with air or gas. Light material such as cotton wool or feathers may be used for filling the balloon.

ROTORCRAFT.

477,349. *Improved Wing Arrangement for Rotary Wing Aircraft.* Asboth Helicopters, Ltd., 48-49, High Street, Bloomsbury, W.26. Convention date (Germany), April 29th, 1936.

It is proposed to make the inner part of the rotary wing blades of zero or small incidence, and an outer part of larger incidence, the angles of incidence gradually increasing from one to the other, the angles of incidence again decrease to the blade tip. The outer blade part may decrease in chord at its inner end.

477,369. *Improvements in or relating to Control Apparatus for Aircraft with Autorotative Wing Systems.* Hamilton Motors (London), Ltd., and Theed, W. O. L., both of 466-490, Edgware Road, London, W.2. Dated June 29th, 1936. No. 17,973.

It is proposed that both the wheel brakes and the rotor clutch shall be controlled by a servo motor deriving power from the suction of the engine. There is a single main control for the servo motors having three positions, in one of

which the clutch is disengaged and the wheel brake applied, in another the clutch is engaged and the wheel brake applied.

480,750. *Improvements in Aircraft of the Cyclogyro Type.* Walton, G. W., 30, Inverness Terrace, London, W.2. Dated Aug. 26th, 1936.

A number of vanes are distributed round the axis of a rotor each being rotatable round an axis substantially parallel to the rotor axis. The vanes are geared to the rotor and they rotate relative to each other with a phase displacement. It is preferred that the vanes rotate in the same direction as the rotor, in the opposite direction to it and at one half its speed.

479,461. *Improvements in or relating to Aero-Revolving Wings or Blades.* Hay, D., 18, Atholl Crescent, Edinburgh, Scotland. Dated Aug. 6th, 1936. No. 21,712.

This specification relates to the rotors of rotary winged aircraft and it is proposed to eliminate the various flapping, drag and inclined pivots at present used by substituting a mechanism in which each blade root is provided with a cross member having ball ends engaged in oppositely inclined elongated slots found in the rotor hub. The ball ends roll or travel in the slots and during normal flight the ball ends are at the outer extremity of the slots with their axis approximately horizontal. When the rotor is being run up preliminary to flight the cross member pivots, with the result that the pitch of the rotor is changed.

483,043. *Improvements relating to Aircraft.* Driver, R. H., 5, Pattenham Road, Perton, near Wolverhampton, Staffordshire, and Share J. B., Merridale Works, Merridale Street, Wolverhampton, Staffordshire. Dated Oct. 7th, 1936. No. 27,173.

It is proposed, in combination with normal wings, to use rotors elongated axially and disposed transversely under the wings of the aeroplane. The rotors have a special cross section which is claimed to induce auto-rotation, and the rotors may be retracted into the wing above them. It is stated that, when auto-rotating, the rotors produce an upward lift, and that a machine fitted with them cannot be stalled.

482,722. *Improvements in and relating to Aircraft.* Fischer, G. A., 47, Second Avenue, Gillingham, Kent, and Mancini, J., Homeland, 29, Marshall Road, Rainham, Gillingham, Kent. Dated Oct. 3rd, 1936. No. 26,824.

The proposed aircraft has flapping wings or wings adapted to rotate about a common axis in which the wings are provided with flaps or shutters, means being provided whereby the position at which the flaps or shutters open or close may be adjusted.

SEAPLANES.

480,923. *Improvements in Devices for Removing Seaplanes and other Similar Machines from the Water.* Etablissements Verboom et Durouchard, 64, rue Campans, Paris, France. Convention date (France), May 23rd, 1936.

The arrangement proposed consists of a slipway inclined between a horizontal portion which can swivel, and a further horizontal portion which floats on the water. The parts can be rigidly attached to each other when the water level is constant, but can be hinged when there are tides. It is stated that the apparatus is suitable for use on an aircraft carrier.

UNDERCARRIAGES.

480,598. *Improvements relating to Shock-Absorbing and Self-Aligning Means for Tailwheels and the like of Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucester. Dated Aug. 22nd, 1936. No. 23,161.

It is proposed to provide a shock absorbing device for tailwheels which will allow of a long travel and also cause the wheel to be self-aligning. The mechanism is contained within a tubular member containing compression springs, and an appliance consisting of a face cam with a face at the angle of 45° kept in contact with a similar cam by means of a compression spring. This appliance returns the wheel to the fore and aft position after it has been rotated on its pivot.

479,398. *Apparatus with a Plurality of Driving Shafts for the Control of Aircraft Landing Gear.* Strube, C., 127, Avenue de Versailles, Paris, France. Dated April 1st, 1937. No. 9,278.

This is an apparatus for controlling aircraft landing gear comprising in combination a plurality of different driving shafts, each of them being adapted to actuate a single driven shaft by means of irreversible transmissions and a differential mechanism, while the driven shaft is adapted to actuate a mechanism connected with the aircraft landing gear.

479,094. *Improvements relating to Undercarriages for Aircraft.* Fandi, F, 5, Bahnhofstrasse, Kronberg, Frankfort-on-Main, Germany. Dated July 28th, 1936, No. 15,475, and July 20th, 1937, No. 20,114.

The proposed chassis has each wheel carried by an inclined shock-absorbing strut pivoted at its upper end. The strut is guided by an auxiliary strut, one end of which is pivoted to the main strut and the other end to the aeroplane. This strut is placed some way down the main strut so that the change of track of the wheel under shock absorption is less than it would be if a divided axle type of chassis were used. The outward movement of the wheel can be largely offset by the inward movement of the wheel due to the relative longitudinal shock-absorbing moment of the two parts of the shock-absorbing strut.

478,778. *Retractable Landing Gear of Aeroplanes.* Mercier, J., 118, Champs Elysées, Paris, VIII, France. Convention date (Belgium), Feb. 24th, 1936.

In this chassis the wheel is carried by a strut hinged in the middle; this strut is hinged to the aircraft frame at one end and is further connected to the frame by a quadrilateral linkage. The landing gear is controlled by a jack which is mounted on the aircraft frame, the head of which has two levers hinged to it, the other ends of the levers are hinged to the aircraft frame and the upper element of the folding strut.

481,288. *Means for Lifting, Lowering or Supporting Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Aug. 15th, 1936. No. 22,537.

It is proposed to provide aircraft with a lifting jack system arranged as part of the undercarriage leg. The jack plunger is telescopically slidable in an undercarriage leg and can be thrust down by fluid pressure, the same means being normally used as are used for the retractable chassis.

481,449. *Improvements relating to Retractable Undercarriages for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Sept. 14th, 1936. No. 25,042.

In order to enable a retractable chassis to be extended if the pressure source fails it is proposed to provide between the cylinder and jack a spring or other resilient medium in which energy is stored during retraction, which energy can be used for extending the chassis.

480,277. *Improvements in Brakes for Aircraft.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, Beharrell, G. E., Wright, J., and Trevaskis, H., all of the Company's Works, Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated Aug. 21st, 1936. No. 23,029.

Hydraulic brake and steering apparatus for aircraft comprising a pair of master cylinders and pistons positioned apart on parallel axes, a member which extends between and engages the ends of the piston rods, rollers contacting with the member, a pressure distributing member or members operating on the rollers and movable transversely of the axes of the said pistons by connection to a rudder bar or pedals, characterised by the provision of a flexible connection connecting the rollers to a hand control, the connection incorporating spring loaded means for the purpose specified.

482,474. *Improvements to Aeroplane Retractable Undercarriages.* Hall, F. H., Cleave Cottage, Holford, Bridgwater, Somerset. Dated Dec. 29th, 1936, No. 35,565, and Dec. 28th, 1937, No. 35,843.

It is proposed to use a cartridge operated jack for operating a retractable chassis. There is a jack consisting of a piston and a cylinder, the piston being connected to the chassis and the cylinder connected to a chamber which holds a gas producing cartridge which can be fired from the exterior. There may be a spring-loaded striker pin acting on a firing pin and normally held cocked by a trigger or trip device.

481,804. *Improvements in Brake Control Mechanism for Aircraft.* Bendix Aviation Corporation, 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), Sept. 18th, 1935.

The braking system proposed has a pair of rudder stirrups each having a brake pedal and a master cylinder associated therewith in such a way that the master cylinder is actuated upon relative movement of the brake pedal with respect to the rudder stirrup characterised in that both the rudder stirrups and the master cylinders are each independently pivoted on a supporting member fixed to the aircraft.

481,946. *Improvements in or relating to the Control of Aircraft Brakes.* Bendix, Ltd., King's Road, Tyseley, Birmingham, 11, and Roberts, G. P., of the same address. Dated Sept. 21st, 1936. No. 25,580.

The control mechanism proposed has valves controlling the supply of fluid under pressure to brakes on wheels on opposite sides of an aeroplane, which valves are mounted with their axes parallel in a casing and are actuated by cam members pivotally mounted on a rocking lever and extending in opposite directions from the pivot, and means operated by a hand control are provided for rocking the lever to advance both cams into engagement with the valves and further means operated from a rudder bar are provided for rocking the cams simultaneously about their pivot to advance one cam and retract the other to actuate the valves differentially.

481,997. *Fluid Pressure Brake and Steering Controls for Aircraft.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, and Beharrell, G. E., Wright, J., and Trevaskis, H., of Fort Dunlop, Erdington, Birmingham, Warwickshire. Dated Dec. 4th, 1936. No. 33,281.

In the pneumatic braking system it is proposed to provide a pneumatic parking apparatus comprising chambers connected respectively to one of the pressure reducing valves, to one of the brake applying means, and to the air container, characterised by valve members coaxially displaceable in one direction against spring load. One of the chambers is formed between a pair of flexible diaphragms converted to one of the valve members, the adjacent ends of which members are normally spaced apart.

REVIEWS.

R. HOFMANN: "DER FACHARBEITER IM FLUGZEUGBAU" (Tradesmanship in Aeronautical Production). Publ. by Carl Marhold Verlagsbuchhandlung, Halle a.S.

A series of inexpensive booklets dealing with the different trades employed in aeroplane construction and maintenance and written for the purpose of general instruction of workmen and apprentices under special training.

Up to now the following parts have been published:—

Vol. 3, "*Der Flugzeugwart*" (The Aeroplane and Engine Mechanic) containing valuable data quoted from maintenance instructions referring to German aero engines and aero equipment.

Vol. 4, "*Der Leichtmetallschlosser*" (The Light Alloy Fitter), giving information with regard to the qualities and the handling of light alloys, with constructional samples.

Vol. 5, "*Der Flugzeugschweisser*" (The Aeroplane Welder).

Vol. 6, "*Der Flugzeugklempner*" (The Aeroplane Sheet Metal Worker).

Vol. 12, "*Der Werkstoffpruefer und Kontrolleur im Flugzeugbau*" (Material Testing and Inspection Duties in Aeroplane Construction). By F. Krause. 2nd edition.

PAUL KETTEL: "KAMPF UM DAS LUFTMEER" (Struggle for the Conquest of the Air). A History of Aeronautics. Published by Wilhelm Langewiesche-Brandt Verlag. Ebenhausen, near Munich, 1938. 288 pages with 76 pictures and photogr. reproductions. Price RM. 4.80.

This book differs from the usual kind of aeronautical history books. It seems to be the first attempt ever made and a very successful attempt to deal with the matter by co-ordinating extracts quoted from contemporary documents. An immense number of interesting excerpts selected from books, newspapers, letters, etc., is connected by a clearly written text in a masterly manner which never becomes doctrinary or tedious. The history before 1500 A.D. is omitted, and the author starts with the efforts of Leonardo da Vinci as the first aeronautical pioneer of whose work facts are known. The book is not restricted to the development of aeronautics in Germany but it refers mostly to it. A bibliography of nearly 400 publications used and quoted from is given.

The aim of the author was not to achieve any completeness with regard to events and facts, but to form a clear and intelligent guide through the aeronautical history. In this the author has succeeded and he deserves full marks for his remarkable effort.

E. TSCHOELTSCH: DER DIENSTUNTERRICHT IN DER LUFTWAFFE. Handbuecher der Luftwaffe. (Instruction Manual for the Air Force). 4th edition. Berlin, 1938. Publ. by Verlag E. S. Mittler and Sohn. 284 pp. with 7 tabl. and 250 pict.

This is a general instruction handbook for recruits and drill sergeants of the German Air Force containing service regulations and all non-aeronautical information considered necessary for the private soldier (uniforms, equipment, health and drill instructions, etc.). The technical and drill instructions refer to carabine, automatic pistol, Dreyse Model 13 machine gun, etc. No reference to flying drill and to handling of aircraft is given.

The 628th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, S.W.1 (by permission of the Council of the Institution), on Thursday, December 16th, 1937, when a paper on the "Development of Sailplanes" was read by Squadron Leader G. M. Buxton, R.A.F.

In the chair: Lord Sempill, A.F.C., F.R.Ae.S., Past-President of the Society.

The CHAIRMAN: The lecture to be delivered was on a subject of very real importance—namely, the development of sailplanes—and the lecturer, Squadron Leader Buxton, as everyone knew, was very well qualified from the technical and practical angle to lay his ideas very fully before them, and he was sure they would have a very complete discussion afterwards.

Squadron Leader Buxton was, as the audience knew, originally at the City and Guilds Engineering College; then he went to Cambridge as a George Carter scholar, and obtained a First Class Honours Degree in Engineering within two years. He was, in addition to that, a founder member of the London Gliding Club, and had also been an honorary instructor of the Club, and he was also concerned with many other aspects of gliding and sailplane activities. Furthermore, in addition to these two activities, he was the designer of the Hjordis and also the joint designer of the King Kite.

It was quite unnecessary to say anything more in elaboration of Squadron Leader Buxton's very wide experience to an audience such as he (the speaker) had the honour to address, and without more ado he would call upon Squadron Leader Buxton to deliver his lecture.

DEVELOPMENT OF SAILPLANES.*

By Squadron Leader G. M. BUXTON, R.A.F.

INTRODUCTION.

This lecture is an attempt to provide a general view of soaring, including the views of the pilot, the meteorologist, the engineer, and the club. If this can be done, it will be easier for each specialist to recognise how he can best contribute to the advance of the pastime.

I think that the technique to build a glider has been available for several hundred years, but the knowledge and desire have only recently grown. The present state of gliding is due to advance in two ways, in art and practice, and in organisation. Perhaps I should not leave out science which is the record of the practice and of the experiments which have been made to improve the practice.

In soaring, which is a sport, it may seem that scientific knowledge has little place. But all theoretical training is training in the knowledge that has been learnt by experience, and the trained man has the benefit of the experiments of the pioneers. It is at least more modest to pay attention to the lessons that others have learnt by reading the standard theory before launching one's own ideas.

* The author is indebted for many of the illustrations to the courtesy of the editor of the *Sailplane*, by whose permission they are reproduced.

I need not dwell on early history. The early gliding of Lilienthal in " hang " gliders is probably known to most people present, and also the fact that he is said to have been risen above his starting point on some occasions when flying his biplane glider. The Wrights studied what Lilienthal had done and realised the shortcomings of Lilienthal's method of moving the centre of gravity of his glider. They designed a glider which was controlled by moving the centre of pressure, and succeeded in teaching themselves to fly it though it was not stable in any way. The Wright machine was soared for nine minutes on one occasion in 1911, but unfortunately they had already fitted a little engine in their machine and were absorbed with the problems of the aeroplane.

A work on aeronautics by Dr. Lanchester appeared in 1908. It was in two volumes, which were called " Aerodynamics " and " Aerodonetics," which is a division of the subject much the same as that in Mr. Warner's two books, " Airplane Performance " and " Stability," of which the former has been published lately.

These books, which give all the information by which a stable and efficient aeroplane may be designed, have been mentioned in the proceedings of this Society often in the last few years.

Chapter IX of " Aerodonetics " is called " Soaring," and I found it a most useful handbook. It does not deal with the details of piloting, but describes the method used by birds. Hill soaring is described, and soaring in thermal upcurrents, though without the modern ideas of thermal bubbles and cellular formation, and dynamic soaring also is dealt with.

I am put out of my chronological order by Dr. Lanchester, as one often is, because his early thought extended so far into the future. I will accept this dislocation and digress to give a short discussion about dynamic soaring for pilots.

It does not seem likely that pure dynamic soaring will be possible for sailplanes. I do not see birds using it, though they have the advantage in their small size and great manœuvrability. The exception to this is the flying in the disturbed air among the waves of the sea; but this is a kind of flying that I will leave to other pilots to try. It may be possible among the rollers of Cape Horn.

Dynamic Soaring.

In 1883, Lord Rayleigh laid down that in order that a bird should consistently maintain its flight, without working its wings, either:—

1. The course is not horizontal. (This is gliding).
2. The wind is not horizontal. (This includes all normal forms of soaring).
3. The wind is not uniform.

Dynamic soaring is soaring in a fluctuating wind.

To understand the possibility of soaring like this, we can think of a simple but improbable case. Suppose we knew that the wind will blow in great gusts of say 50 miles an hour first westwards and then eastwards at regular intervals. During a lull the pilot faces his sailplane towards the oncoming gust, which lifts him into the air when it reaches him. As he rises, he turns until he is flying with the wind at great speed over the ground. The wind then lulls, but this gives to the pilot, flying with the wind, an increase of his air speed. As the gust lulls he climbs more and still more as the gust from the opposite direction grows until the new gust has reached its greatest strength, when he turns down wind again and again benefits as the gust lulls. Thus he continues to climb.

This is comparatively easy to understand because we have thought of the average wind as zero. But if there is a gusty wind blowing in one direction the mechanics of the process are the same, but the pilot will be travelling with the wind at its average speed.

It seems clear that actually it is impossible to fly like this because the pilot does not know when the gust will lull or when to turn the sailplane to take advantages of the change.

I have heard of an actual example of this effect. Unfortunately it happened in the opposite way to the way I have just described and the aeroplane fell.

A military aeroplane in India was coming in to land, and just after it had crossed the edge of the aerodrome it fell to the ground. The pilot, who was not hurt, said that he had been flying at an adequate speed, and a witness said that he had seen the wind change its direction completely at that moment; though the pilot began coming in against the wind he had suddenly changed to an area where he was coming in with the wind. The wind had been about 16 m.p.h. against him and became about 5 m.p.h. with him and so reduced his air speed by that amount, which was greater than the margin between his flying speed and his stalling speed, so he sank to the ground.

It can be shown that to get maximum energy from the wind, the sailplane must act on it in such a way as to reduce the variations, or rather to eliminate them so that the wind speed is uniform. Thus it must press on the lulls and press back the gusts. One way to do this is by climbing and diving. Suppose the pilot is flying against the wind, then as it increases he must climb steeply enough to retard the air in which he is flying and then when the lull comes he must dive steeply enough to accelerate the air in which he is diving. Thus as he evens the speed of the wind he obtains energy, which can be shown if the reactions of the sailplane on the air are worked out.

Here again the manœuvres for dynamic flight are alarming, and as the most perturbed air with the greatest amount of available energy is near the ground it seems that this method of flight is not likely to become popular. This description is intended to make the fundamental basis of dynamic soaring clear to pilots. For those who are interested there is a fuller discussion in Dr. Lanchester's book, and also in Herr Lippisch's lecture.

The possibility of dynamic soaring has not yet been settled. It may be that the new statistical information on the possible turbulence of the air which has been published lately can be used to show whether dynamic soaring is theoretically possible with the sailplanes that are available.

Help from Dynamic Effects.

I discuss these effects in terms of the motion of the sailplane relative to the air surrounding it. They can, of course, be discussed in terms of the motion of the sailplane relative to the ground, but the discussion becomes more complicated if this is done.

But although pure dynamic soaring has not yet been used successfully, it is possible to get assistance from dynamic effects while soaring in other ways.

The most familiar one is the gain of energy when rising from the ground against the wind. The reason for this is simple and well known. Owing to friction with the earth, the velocity of the wind increases with the height from the ground, increasing rapidly in the first few feet from the ground. Thus the sailplane moves into air of greater velocity as it rises and so gains energy which assists its climb or increases its air speed.

The reverse of this effect is that there is a loss of energy when sinking to the ground against the wind. As the ground is approached, the velocity of the air decreases and the rate of loss of height is more rapid than it would be in a uniform air stream. But conversely if the sailplane is landed with the wind it is meeting air whose velocity relative to itself increases as it descends so that its rate of descent is less than it would be in a uniform air stream. This case is interesting for sailplane pilots because it is often convenient to make a down wind landing. If unable to soar, the pilot can turn towards the hill and land with the wind and up the hill and thus avoid going to the bottom. Or in hilly districts he may like to do this to avoid the turbulent air in the valleys and behind the hill. Although I hope that nothing that I say here will prevent pilots having ample speed when

doing this manœuvre, it is clear that the dynamic effect will give a little useful help to the machine as it is being pulled up to land on the hill.

Another similar case discussed by Dr. Lanchester is that of soaring near an obstacle (Fig. 143 " Aerodonetics "). The obstacle illustrated is an oblong one like a house in plan view. A path of a bird is shown and it is clear that if the bird enters the dead water, or rather dead air, in the lee of the house when flying down wind, and turns while in the dead air, and leaves it when flying up wind, it will gain energy on entering it and on leaving it.

It may not be practically convenient to fly round a house in this way in a sailplane, but a similar effect is produced by the configuration of the ground in various places, one of which is the bowl at the north end of the soaring ground of the London Gliding Club at Dunstable. This ground is a straight ridge facing west and at the north end of it there is a projection from the ridge which forms a bowl which faces south.

When conditions are very smooth, it is possible to fly straight into the bowl and over its crest, and then to turn to the left while just above the top of that part of the hill and so come out over the plain again.

By doing this when the wind is in the south, the pilot finds an increase in air speed when he flies into the bowl down wind as he crosses the crest. This is due to the stagnation of the air behind the crest. He can then turn in the stagnant air and will again experience an increase of air speed as he emerges into the wind as he comes out over the plain. In smooth conditions when it is possible to fly over the crest of the hill at a low height, continuous circles over the bowl can be made, using this effect to reinforce the hill lift.

Basis for Using Dynamic Effects.

The wind must be acted on horizontally to reduce its horizontal variations. Of the parts of a sailplane, the wings are designed to act on the air in a vertical direction and other parts are designed to act on the air as little as possible. Thus to act powerfully on the air in a horizontal direction it is necessary to bank or to pitch the sailplane so that the wings can be used. The need is to discover ways of doing this without making the manœuvres so violent that more is lost in making these manœuvres than is gained from the dynamic effect.

When considering the movement of the air, it is clear that a horizontal gust cannot exist without a vertical gust, which should also be used in any system that is planned to exploit this energy.

Progress until 1931.

We now return to the point from which we started this digression. The Wright brothers as potential soarers. I will summarise very shortly the history of the progress from then until 1931.

This period started soon after the war with great efforts made in the hope, rather faint and improbable, that soaring might be possible. In 1922, Hentzen and Martens made a soaring flight of an hour at the Wasserkuppe in the Vampyr from Hanover, which is the first example of the modern sailplane. It had an enclosed fuselage, cantilever wing with a single spar, and in fact was very similar to the modern refined sailplane.

Then the Roemryke Berge was designed in 1924 by Schatsky. The fuselage is oval. the wing is cantilever with a thin section and has trailing edge flaps. This machine was not successful until Nehring flew it, when it made an historic distance flight.

In 1926, Max Kegel, when hill soaring, rose into a thunder cloud and flew a distance of 54 km. In 1928 Kronfeld made flights under clouds. I do not know who first flew on a cold front, Groenhoff or Kronfeld, or someone else. The last and perhaps the prettiest development of thermal soaring is largely due to Herr Hirth.

THE CONSTRUCTION OF GLIDERS AND SAILPLANES.

Alexander Lippisch gave a lecture, The Construction of Gliders and Sailplanes, to this Society in January, 1931. He was then Director of the Technical Department of the Rhon Rossitten Gesellschaft, the guiding authority of the pastime in Germany at that time, and his paper is the product of great experience and a record of great success. It is still the last word for all that it deals with. For example, the sailplane that won the International Competition at the Wasserkuppe this year was the sailplane whose prototype Lippisch was designing when he read the paper.

DEVELOPMENTS IN ENGLAND.

The new beginning of gliding as a sport in England was at Itford in 1922, where, on the last day of the competition, a world's record for duration was made by Maneyrol in a tandem Peyret monoplane with a flight of 3 hours and 21 minutes. The effort roused by this beginning was diverted by a competition the next year for small power machines, which were given the unfortunate name of power gliders, in an attempt to harness the attractions of soaring to this utilitarian purpose. The art lay dormant in England until the revival in 1930, of which the chief feature was the tour of Herr Kronfeld with the Wien and Herr Magersuppe with the Professor.

Much enthusiasm was roused and clubs were formed all over the country. At one time there were more than 100, but of these only half a dozen or so have survived.

The problems of having a gliding club were not able to be solved by the methods that were adopted by the majority of the clubs.

The British Gliding Association, which was set up as a central organisation, was not able to give financial assistance to clubs except by the means of providing them with gliders on hire purchase terms nor was it able to provide the technical advice in the form that was needed.

The material problems were those of the provision of flying grounds, hangars, club houses, and aircraft. The provision of flying ground is itself a major difficulty. A ground which is large enough and has the slopes facing the prevailing wind which are needed for soaring is probably more difficult to find than a flat ground suitable for an aerodrome. The hangars that are wanted for gliders are similar to those that are wanted for light aeroplanes, and a similar club house is needed.

The last, and from the point of view of capital outlay, by no means the greatest requirement is aircraft to fly. By comparing the income of the small clubs that were formed with the capital that was needed to provide the necessary equipment, it is clear that these problems could not have been solved.

Even if these problems had been solved, there was the problem of teaching soaring to the members of the club, when there were few or no instructors in the club capable of soaring. I say instructors, by which I mean the men who were asked to instruct and who were willing to give their time to do so. The fact that many of these knew little or nothing about soaring meant that the number of minor accidents and the amount of damage to machines was great.

I was a member of the London Gliding Club while it was struggling to survive and the fact that it did survive is, I think, due mostly to the obstinacy of the members.

At the same time the direction of the club was very successful in doing a great deal with small means.

The London Club was, I think, the first club to realise that a subscription of one guinea was inadequate, and so the subscription was trebled.

The first flying ground that was continuously used was that at Ivinghoe Beacon, which was the property of the National Trust.

In selecting a permanent soaring site, the primary requirement of good soaring conditions was kept firmly in mind, and the whole of the Chiltern Hills and the North Downs, and even of the South Downs, were searched before deciding that the ground at Dunstable was the best.

During the first months of operation at Dunstable the machines were housed in a farm barn where all, even the primary, had to be dismantled.

The transition from this to the possession of a club house was a feat that exhausted the finances of the club, and even put a strain on the enthusiasm of the members.

During this strenuous time a large proportion of the hardest workers in the club were members who lived near it. I think that this was fortunate, for I think that a few extremely keen and able members can do more than a number of keen members who are not able to make a continuous effort.

The strongest factor in the survival of the club was, in my opinion, the efficient conduct of the flying instruction. Of course, it was not at first efficient, but the first four C certificates in England were gained by members of the club and the efficiency grew. In February of 1931, the first two *ab initio* Cs were gained by Smith and Graham Humby, who then became instructors. Graham Humby was a born instructor and did an extraordinary amount of instructing at that time.

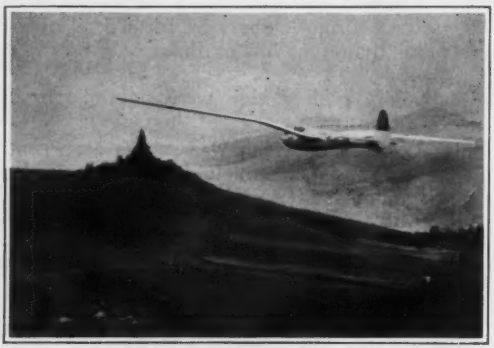

FIG. 1.
Reiher.

Marcus Manton, who was the chief instructor of the club, was an instructor of flying of 20 years' standing. It was his standard of safe and skilful piloting that gave a sound foundation to the flying of the club.

To return to high performance flying. The aerodynamic problems were understood by the year 1930 and I do not think that there has been any advance in plain performance since that date. The progress since has been made by increasing the stability and manœuvrability of sailplanes and by improving piloting technique and meteorological knowledge. The requirements of cloud flying have brought a demand for stability and strength.

To give an idea of the state of the art at that time, it is interesting to look at the Wien, the Kakadu, the Fafnir I, in which can be seen very clearly the origin of the Sao Paolo and the Austria.

The Wien is a strutted sailplane of high aspect ratio and low structure weight. The wing section used is Göttingen 549 with slightly increased centre line curvature near the root. The modern demand for manœuvrability was met by the use of ailerons with differential control and by a flattening of the section towards the wing tips to give good lateral control. It is a development of the Professor.

Lippisch stated in his lecture that the resistance of the strut was largely offset by a reduction of the resistance of the wing owing to the wing section being thinner than the section that would be necessary in a cantilever wing. It is interesting to observe that the Reiher, the new German cantilever sailplane, uses this same wing section. Whether it is necessary to use so thin a section in a cantilever wing may still be a question, but that it is possible is no longer in doubt.

The Kakadu is interesting for the method of construction and the very low structure weight. It is a cantilever sailplane of 62ft. wing span with a wing section, Göttingen 652 at the root and related sections towards the tip, which is awkward for structural purposes, yet the structure weight is only 320lbs. empty. (It is fair to remember that the factor c.p. forward was probably only 6 compared with the factor of 8 which is more usual to-day.) Weight was saved by carrying the bending stress in the ply skin of the wing; there was no spar as such, the shear loads being carried by a ply web.

The Fafnir which was one of the first, if not the first machine, to have a gull wing, had a wing construction somewhat similar to that of the Kakadu. It had three shear webs at the root and of these two ran out and one continued to the wing tip. Lippisch had such faith in Günther Groenhoff, who was to fly it, that he was able to confine the view to two small holes, about the size of one's hand, one on each side of the pilot's face. Groenhoff did many fine

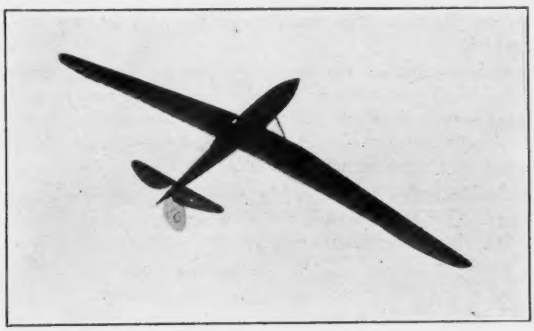

FIG. 2.
Scud II.

flights in these conditions and did not seem to be much hampered by a restriction of the view that would raise great objections from most pilots. In spite of this, the aerodynamic problem of merging the wing into the fuselage was not solved at first and it was not until three considerable modifications had been done that the solution was found.

I saw this sailplane in a museum in Berlin this year, with its final wing body arrangement which is somewhat similar to the one used in the Sao Paolo.

The preservation of this most interesting sailplane is also perhaps the best memorial of Günther Groenhoff, the great pilot who used to fly it.

I might mention a contemporary English glider, the Scud, of about 40ft. span which was designed by Mr. L. E. Baynes. It was very pleasant and responsive to fly and at the same time was very stable, though to find the stability the control column had to be held fixed as the elevator was all moving. The same was true of the rudder.

It had a very ingenious square body of small cross section. Mr. Baynes was severely criticised at a later date for making the cockpit so uncomfortable, and

could only defend himself by saying that it was most comfortable, as it was, for the person for whom it was designed.

The tip chord of the tapered cantilever wing was 0.33 of the chord at the root, a ratio which we have returned to after an excursion to higher taper ratios.

When calculating the load distribution, it became apparent that the loading at the tip was greater than the loading at the root, that is to say, that the lift coefficient at the tip was greater than at the root.

In addition, the Reynolds number at the wing tip is less than at the root, so that the tip in similar conditions is more likely to stall.

Those who are acquainted with the ordinary calculations on a tapered twisted wing will remember that the mathematical device by which it is calculated is to assume that the lift coefficient is proportional to the incidence and then to calculate the state of affairs for incidences at which the designer sees that this will be substantially true. The calculation does not show what happens at the stall, nevertheless it is fairly clear that if the wing tip is working at a higher lift coefficient than the wing root, the wing tip will be likely to stall first. We did not want to test this point and Mr. Baynes selected a twist to the wing, decreasing the incidence towards the tip, such that the lift coefficient decreased towards the tip.

The effect of this was satisfactory, and the Scud had nice characteristics in roll even when the incidence was near the stall. I believe that aircraft have been built where this principle was not followed, and that the result showed that the assumption that the tip was likely to stall before the root has been shown to be justified.

This simple consideration of the problem has to be modified by information that has been published, particularly by Mr. Irving of the R.A.E., on the effect of sweep back and sweep forward on the stalling of the wing. However, most gliders have a straight spar at about a third of the chord so that they do not vary in this respect and results are comparable.

Dr. Kupper, who designed the Kakadu, next designed the Austria, which was first flown in 1931. This is perhaps the most remarkable sailplane that has yet been built. Its characteristics were:—

Span	30 metres (98ft.).
Wing area	34.97 sq. metres (376 sq. ft.).
Tailplane and elevators	3.33 sq. metres (35.8 sq. ft.).
Rudders and fins	2 × 1.04 sq. metres (2 × 11.2 sq. ft.).
Complete wing and ailerons ...	263.3 kg. (580lbs.).
Tail unit	31.1 kg. (68.5lbs.).
Body, skid and instruments ...	98 kg. (216lbs.).
Weight empty	392.4 kg. (865lbs.).
Pilot	70 kg. (154lbs.).
Parachute	7 kg. (15.4lbs.).
Flying weight	469.4 kg. (1,032lbs.).
Wing loading	13.43 kg./m.^{2} (2.75lbs./ft.^{2}).
Span loading	0.52 kg./m.^{2} (0.106lbs./ft.^{2}).

This low structure weight is the more remarkable in a wing that was fitted with flaps.

The fuselage structure is most interesting. In the usual form of sailplane, the fuselage weight is caused more by the need for a reasonably robust structure for handling on the ground than by the needs of strength when flying. In the Austria the fuselage is contracted until it is really a form of tail boom in which the stresses caused in flight require a structure which is very robust. This boom does not carry any landing loads.

The sailplane is prevented from tipping back when on the ground by a stiff rubber pad under the back end of the skid.

Soon after this I began the design of a sailplane for myself which was eventually called Hjordis. I did a considerable preliminary investigation on the question of size, aspect ratio and so on, which was based on the propositions ("Aerodynamics," Chapter VII) expounded by Dr. Lanchester and the information provided by Herr Lippisch.

The sailplane was designed for best gliding angle, which leads to slightly different results than a design for lowest sinking speed.

It became apparent that a moderately good performance could be got with a span of 50 feet, which was the greatest size that I thought would be convenient for myself or indeed for any private owner. With this span it seemed advantageous to accept a high wing loading and keep a small wing area, the corollary to this being that the fuselage resistance would have to be as low as possible so that the fuselage would not set up too much drag at the comparatively high speed at which the machine would fly. The result was a sailplane of 51ft. span, one foot more span having been stolen from the centre section fitting, an area of 123 square feet and an empty weight of 350lbs. or so which has since increased considerably owing to the repairs and new coats of paint and so forth.

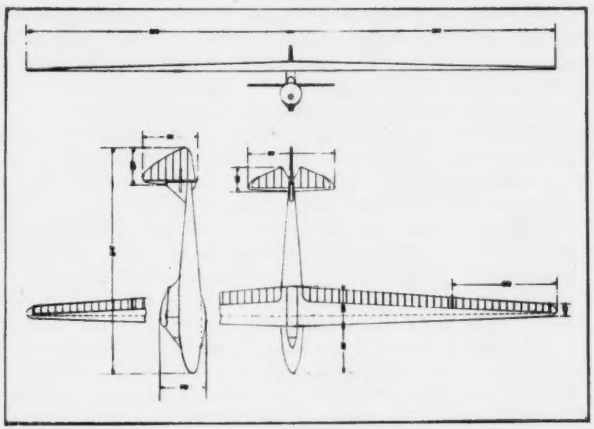

FIG. 3.
Hjordis I.

The wing has a taper ratio of 4:1 and a total twist of 6°. The wing section at the root is Göttingen 652. At the middle of the semi-span it is a calculated section similar to this, but thinner and calculated to give the aerodynamic twist that was needed without a change of rigger's incidence. The wing section at the tip is R.A.F. 32, which also gives the right amount of twist without any change of the rigger's incidence. Thus the wing has considerable aerodynamic twist and at the same time all the ribs would touch a flat bench in two places and so is fairly easy to construct and yet has good stability near the stall and good lateral control.

The controls are not suited to modern flying. The elevator is all moving and there is a small fin to the rudder. Thus the elevator is very sensitive, and the tail load is felt by the pilot and is quite large at high speeds. While it may be thought desirable that the pilot should be able to feel what is happening in this direct way, it is a disadvantage in practice because it tends to confuse the pilot while he is recovering from a dive.

A larger fin would give more directional stability, which is, I think, desirable for cloud flying.

The rudder is rather big. It was originally meant to be a split rudder so that the pilot by pressing on both the rudder pedals simultaneously could open the rudder out, the two sides coming apart, and so have an air brake when coming in to land. But among a number of new developments in construction this additional one seemed to be not entirely necessary, and was dropped.

The ailerons were found to be unsatisfactory. The torsional deflection at the ends was several degrees when in flight. Also it was found that the wing was not strong enough in bending near the ends to support the wing tip on the ground if there was a wind tending to lift the other wing tip. Both these troubles were met in the same way, by putting a thicker ply covering on the outboard part of the wing which strengthened it in bending to a considerable though uncalculated degree, and by putting thicker ply on the top and bottom sides of the box spar which carries the torsion from the central aileron king-post and distributes it along the aileron.

The fuselage is circular in section and covered in ply. There are four longerons inside which are strong enough to take the bending moments. The only interesting part of the structure is the neck, which gave me a lot of thought because I had seen a fuselage twist its neck off in an easy cross wind landing in Germany. If the machine was to be suitable for the English private owner, or at any rate for me, it would have to have a strong neck. For this strength I used the strength of the main spar of the wing. The centre main fitting is bolted on to a spar which runs down the neck to the skid and is calculated to withstand a side load of twice the total weight, that is to say, of about half a ton, at the skid. This prevents the fuselage from rolling from under the wing, and it is then necessary to prevent the fuselage twisting off the wing by wringing the neck. For this there is another spar in the fuselage taking off the rear wing spar. If the wing tries to twist off the fuselage, a thrust in the wing rear spar tries to bend this fuselage spar and thus puts a torque in that part of the fuselage between the two fuselage spars. All these parts are built to take the stresses caused by a load applied backwards at the wing tip of 110 lbs.

It was interesting to see Hjordis after a crash which she had once had, in which one wing tip had hit the ground first and had broken off. The break was about half way down the wing, at a point where the section of the spar is of considerable size. The damage to the fuselage was a break all round the base of the neck, which would clearly also help to resist the wing twisting off, though it was not part of the primary structure for this, and a break in the ply between the bulkheads which carry the spars in the fuselage attached to the front and rear wing spars. These fuselage spars were not broken.

One other feature of the control of this machine is that the ailerons are controlled by a wheel like many commercial aeroplanes. It is not a big or convenient wheel and has been a hindrance to the popularity of this machine, as glider pilots in this country are not accustomed to wheel control.

Present Practice.

Soaring is an art as well as a science, and I hope that those who are interested in this lecture will go out to a gliding club and learn more by practising.

In brief, soaring may be divided into hill soaring and soaring away from hills.

Hill soaring is easy to explain and must be familiar to everyone here. It is done by flying in the rising air deflected upwards by a range of hills or by some other obstacle when the wind is blowing. No great distance flights have been made in this way in England, for little flying has been done in those parts of the country where this might be possible, but it is possible to make long distance flights by these means if there are continuous ranges of hills available.

The height that can be gained in hill soaring is limited and is usually found to be about three times the height of the hill in good conditions and when the hill is moderately small.

FRONT SOARING.

The front is the line of meeting of warm and cold air masses. Here in the northern hemisphere the south-west quarter of the depression is normally a warm sector and the other three-quarters are cold. The cold front is the front between the westerly warm wind and the northerly cold wind. The other front where the warm wind meets the cold wind is an area of slighter action. The gentle drizzle and slight temperature change in a warm front do not seem likely to produce up currents that would be large enough to use for soaring.

At the cold front the northerly wind, which is cold and therefore heavy, cuts under the westerly warm wind and at the point where they meet, where the warm air is rising over cold air, there are up currents which are large enough to be used for soaring.

The figure shows a cross-section of the front. It shows the heavy roll of cloud which is characteristic and which has caused the name line squall to be given to the more strongly developed fronts. The cold air is seen coming in, and just under the cloud and in front of the cold air there is an area of strong up currents. Inside the cloud the rising of the air is reinforced by the liberation of latent heat, and it is common to meet very strong up currents, often accompanied by violent rain, or hail and lightning, in the clouds above cold fronts.

An interesting paper on this subject was read to this Society by the late Mr. Giblett. (Journal of the Royal Aeronautical Society, June, 1937).

One feature which is important to the pilot of the sailplane is that the most advanced part of the cold air is at a height above the ground. The strongest up currents are just before this position and are fed by the air that has been trapped under the advancing cold air as well as by the warm air that is just in front of it.

As the best up current is at some height above the ground, the pilot must be at a certain height before he can hope to be able to make use of a front. The method that is most usual is to gain the initial height by hill soaring, though it would, of course, be easily possible to do it by means of an aeroplane tow. It may happen that the conditions are not very good for hill soaring, although the pilot had hoped to use this method, in which case it is better to delay the launch until the front has reached the hill rather than risk being forced to descend before it comes. The usual saying is that the launch should be made just before the rain if this plan is followed, but I should hesitate to give that as a fixed rule. Groenhoff, at the beginning of a great flight which he made on a front, was launched after the front had passed, but he diagnosed what had happened and flew straight down wind regardless of loss of height to catch it up.

The figure shows a cloud neatly arranged in a convenient position, but in practice the difficulties of diagnosing one's position in the front are often increased by the ragged pieces of cloud formed in the rising air before the front and obscuring the form of it.

It is often possible to make a flight before the front far enough away from it to avoid the clouds and if this is done the pilot may expect to have a quiet and pleasant ride, being able at any moment to descend by flying away from the front or to rise by flying closer to it. On the other hand, he may find that however close to the clouds he flies he loses height; then he may either enter the cloud, for which he needs all the equipment and experience described below for cloud flying, or if he has not got the equipment and experience he must give up and fly away and come down.

If the pilot enters the cloud he is likely to find quite vigorous action and to be able to reach a considerable height. The inside of the cloud may be smooth, with huge volumes of air rising up together, or it may be very rough. If there is hail it is clearly likely to be very rough indeed and the sailplane may become uncontrollable if the pilot has not got the means of escaping from the cloud and is drawn up into the turbulent region.

Dr. Georgii holds that there is a kind of rolling action in the cloud with the air of the forward side rising and the air of the rear side falling so that the pilot should try to stay near the forward part of the cloud. If he does this he may also be able to fly out of the cloud on its forward side and away from the front when he wants to. It should be quite possible for the pilot to come out of the front of the cloud from time to time into clear air and look at the cloud and find his position before going back into it.

THERMAL SOARING.

Thermal soaring can only occur when the atmosphere is unstable. If the dry adiabatic lapse-rate, that is, the decrease of temperature with height, is above 1°C. per 100 metres of height the air is unstable, so that a volume of air warmed to a temperature above that of its surrounding air will start to rise and continue to rise, for the temperature of the surrounding atmosphere will decrease in temperature as fast as the temperature of the warm air decreases from its expansion as it rises into regions of lower pressure.

In practice it is found that there are a number of days in summer when the atmosphere is unstable and when there are up currents great enough to be used for soaring by sailplanes. A rate of climb indicator is needed for this, and no one was able to do thermal soaring in this country until one had been developed.

In 1931, great efforts were being made to produce a rate of climb indicator. There were four lines of development. The pressure of the atmosphere decreases with height. Four systems of measuring the rate of decrease of pressure, and thus the rate of gain of height, were developed. A bottle with an outlet is used for each system, the flow through the outlet being measured by four methods.

To do this the outlet of the bottle can be restricted and the pressure across the restriction can be measured by a sensitive pressure gauge, or the flow of air can be used to cool a wire which is heated by electricity and the cooling effect can be measured electrically, or the actual flow can be shown in two ways. In all practical instruments the flow into the bottle is measured to show the rate of descent as well as the flow out of the bottle which shows the rate of rise.

The first successful instrument for the gliding movement was made by David Dent, who used a restricted outlet with his bottle and devised an extremely sensitive pressure gauge on the principle of the U tube. He increased the sensitivity by using two fluids of slightly different density balanced against each other so that the reading, being proportional to the difference of their densities, was reasonably great for a very small pressure; and he eliminated the effect of banking or of fore and aft accelerations, which would make the readings of a U tube useless, by making one arm of the U tube concentric inside the other.

Eric Collins used this invention in a masterly way to make the first thermal flights in England. He was acting as instructor during the British yearly competitions in 1933, which were held on a site where no hill soaring was possible for most of the month during which they continued. He had a two-seater B.A.C. instructional machine of moderate performance which was launched by a towing car. With this equipment and with the Dent variometer he made a number of thermal flights alone, and with his wife as passenger. There is no doubt that these flights were true thermal flights as the wind was blowing down the hill during some of them.

It was quite apparent that if thermal flights could be made off the winch with a two-seater of low soaring performance, it would be comparatively easy to do them with the same instruments under better conditions. Though there was little result during that year, thermal soaring was commonplace the next year, and now, five years later, there are about 30 silver "C" badges awarded in England compared with 40 of the much easier "C" badge that had been awarded then.

In other variometers that have appeared a mechanical instead of a liquid pressure gauge has been used. The electrical system was not developed in the face of other and perhaps simpler systems. In the Slater Cobb the air from the

bottle flows through a tapered perspex tube. The flow of air supports a small ball which rises up the taper until the space round the ball is large enough to release the air. The pilot judges the rate of rise by the height to which the ball has risen against a scale by the side of the tube.

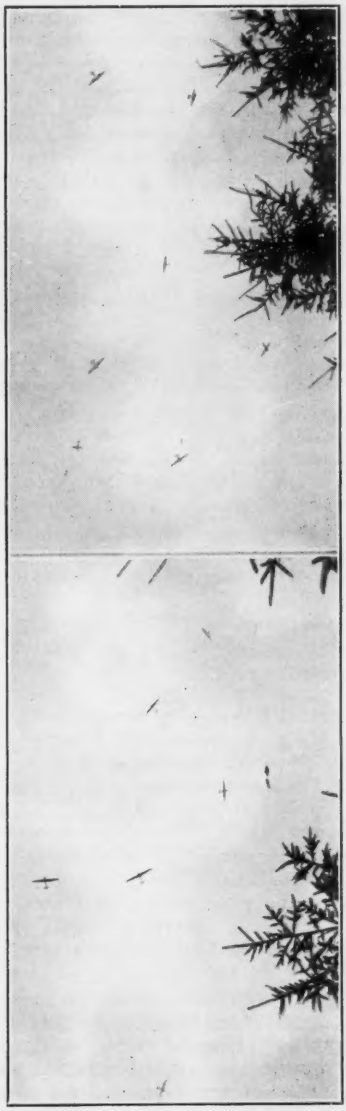

FIG. 4.
Sailplanes circling in a thermal.

A bubble is used to show the flow of air in the latest, and perhaps the prettiest, method that I have heard of. The outlet to the bottle is a glass tube, and a soap bubble is blown in this glass tube. The soap bubble floats in the air and moves with it showing the smallest movement, so that a measure of

change of height is given by the movement of the bubble. The displacement of the bubble shows the change of height.

The preliminary to thermal soaring is to get away from the surface of the earth. As Dr. Lanchester has pointed out, the surface of the earth is a boundary surface and it is impossible to find an up current immediately adjacent to it. The corollary to this, that the up current must be supplied by a horizontal inflow below it, is often of use in detecting the position of up currents, for the tails of smoke and of wind indicators will be deflected towards the up current.

The pilot may reach a height above the surface of the earth to a height where the up currents are well developed by hill soaring, or by a tow from an aeroplane, or even by a launch by an auto tow as Collins did first, though this is the most difficult. If he is hill soaring he will soar as far in front of the hill as he can while searching for a thermal. When he feels lift and sees from his variometer that he is rising, he circles and seeks to adjust his circle so that it is entirely within the up current. As he travels with the wind, he will soon be over the crest of the hill and he must then judge whether the thermal up current alone will be strong enough to sustain him if he goes with it and leaves the hill.

There is not a great deal of experience in this country of finding thermals by aero towing. If there are enough thermals to make a good cross-country flight possible, it is only necessary to be towed to a considerable height and then to cast loose and slow up to soaring speed and look for a thermal. But it is clearly an advantage to continue in tow until a thermal is actually found. This is apparent for the aeroplane if flying steadily is seen to rise. There is then little time to be lost. The tow must be released and the sailplane slowed and turned as quickly as possible. Clearly if the towing speed is 60 m.p.h. and the thermal is 300 feet in diameter, it will only take three seconds to go through it.

The circle should be flown as tight as is necessary to keep within the best up current. Even though the sinking speed is considerably increased by doing this, the benefit from the better up current is likely to be greater.

The spacing and structure of thermal up currents has been studied in the last few years.

This is discussed in the G. J. Symons memorial lecture of March 17th of this year, which is in the Quarterly Journal of the Royal Meteorological Society, Vol. LXIII, No. 271, July, 1937.

A more general book which may serve as an interesting introduction is "Weather Science for Everybody," also by Professor David Brunt, which contains information that bears on soaring.

Thermal up currents and down currents occur in a regular cellular formation when the air is unstable and when there is no wind. The up current forms the core of the cell, and its area is a quarter of the area of the down current. It follows, since the flux through any level must be zero, that the mean velocity in the core must be four times the mean velocity of the down current round it.

If there is a light wind the structure changes and rolls across the wind are formed. If the wind is strong there is a third kind of structure which often seems to be more clearly defined than the other two. The rolls are formed in the direction of the wind and when marked by clouds are often seen stretching as far as the horizon.

The pilot may be soaring in a thermal in order to make a duration flight, or for height, or to make a distance flight. For height he will climb as far as cloud base and will then probably have to enter the cloud, and I discuss later what happens then. For duration he may devote all his energies to gaining height unless he wants to stay in one position, when he must make enough progress against the wind to cancel its effect.

It will save time to discuss only the most difficult thermal flight, the distance flight.

The easiest way for a pilot to make a distance flight is for him to confine his attention to gaining height by circling in thermals, and to drift with the wind as

long as he is able to keep in the air. Conditions may be so bad that he is compelled to devote all his attention to keeping in the air in this way, or the wind may be so strong and in such a convenient direction that he is making as much progress as he desires while doing this.

But if the pilot desires to go in any direction that is not straight down wind he must decide to make a compromise between gaining height in thermals and gliding through regions of down currents in the direction that he wants to go.

It may happen in very good conditions that he can make this compromise while flying straight in the direction that he wants to go by flying fast through the down currents and flying slowly through the up currents. If he can do this he will be able to make a great flight. But usually he will have to circle in thermals to gain height and use the height to glide in the direction that he wants. While he is circling he is drifting with the wind and he is only improving on this

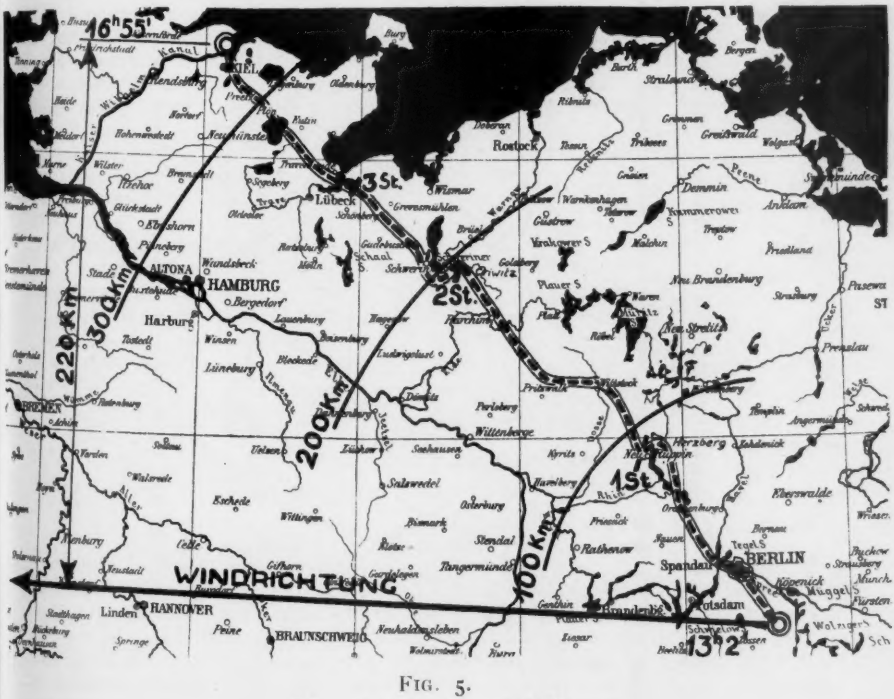

FIG. 5.
Map of Rotter's goal flight.

when he is gliding down. The question for the pilot to decide is when to continue circling in a thermal and when to leave it and glide straight. Clearly the pilot must find out the height at which the thermals are most vigorous and fly at that height.

The lapse-rate which measures the instability of the atmosphere, and so the strength of up currents, is not constant at all levels. On any day there will be certain heights where thermal action is most vigorous.

The pilot may decide that some height, say 1,000 metres (3,280 ft.), is the lower extent of the region of most vigorous thermal action and he will then know that so long as he is above this height he must stay in a thermal only so long as he is rising rapidly in it. When he has gained some height he

must not hesitate to push off and fly straight until he finds another good one. As the flight progresses he will notice the heights at which he finds the strongest thermals and so will be able to vary the height that he first decided on. He will

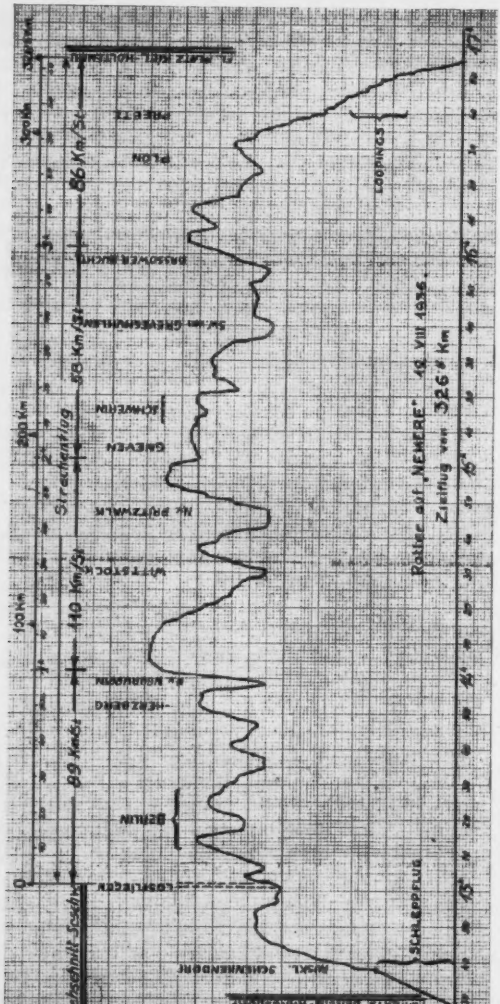

Fig. 5d.
Barograph record of Herr Rotter's goal flight.

also get an idea of the distance between thermals, and of the height he is likely to lose after he has left a thermal before he finds another, which will assist him to judge when he should leave a thermal.

The flight by Rotter, from Berlin to Kiel, is a fine example of a thermal distance flight. On the day before the flight, he forecast that the weather would be suitable.

A large part of this flight was made without circling, but he had to circle at times. The map of the course and the barograph record is shown. The barograph record shows clearly that he was careful not to descend below a definite height, which he must have judged to be the minimum for active thermal up currents.

The general instability of the air, particularly of the lower layers, and the local heating of bubbles of warm air depend on the type of ground on which the sun is acting or has acted. The information about this is empirical and somewhat conflicting. It seems that a cornfield often is a source of heat for warming the air and thus causing thermal bubbles to form. Towns with their red roofs absorbing and radiating the heat of the sun have often been found to cause thermal bubbles and big towns particularly do this, possibly owing to the amount of heat given out by industrial processes as well as the heat they get from the sun. Woods have been said to cause down currents over them, and they have also been said to cause up currents. It may be that they absorb the heat and slowly gain temperature in the morning and, keeping the heat better than other areas, give it out later in the day. The woods of Germany seem to be specially good as sources of thermal up currents; these woods are often of scots pine, growing on light sandy soil which may contribute to this effect. The ground at Dunstable seems to be rich in thermals, which may be due to the nature of the ground which is chalky.

Water has a big capacity for heat and so behaves in the same way as I have described in the supposition of the behaviour of woods. Thus if the ground is cooled quickly, say by a cold wind, a patch of water is likely to remain warmer than the ground and so to be the cause of up currents. This is likely to happen in autumn, and I expect that it will be found easier to fly the channel in autumn than in spring. Conversely if the ground has been heated quickly, the water will be likely to be cooler and will have down currents over it.

These heating effects are surprisingly local, and I have, when flying an aeroplane, felt a considerable bump over a black tarmac road which was only about 35 feet wide. Perhaps someone will make a great distance flight along a road before they are all turned into white concrete.

Cloud Soaring.

A cloud begins to form if air containing moisture rises and is cooled by rising to its temperature of saturation. As the air rises above this level its temperature decreases so that its capacity for moisture decreases. The moisture gives out latent heat as it condenses. This latent heat being given out reduces the rate of cooling of the air as it rises, so that the atmosphere is unstable (if the air is wet) at a lapse-rate lower than the dry adiabatic. The saturated adiabatic lapse-rate varies with height and with temperature and is approximately 0.56°C. per 100 metres. It is impossible or at the least it is unusual to fly when the cloud base is at the level of the ground, so that the pilot must first ascend by any of the means which we have discussed.

It is known from many experiences that violent conditions may be met in clouds. An idea of how violent the conditions may be is got by thinking of hailstones. Hailstones are maintained or raised in the atmosphere by up currents while they are being formed. Hailstones as big as a pigeon's egg are found. So that most pilots, after thinking about this, will not want to be present at the formation of them.

For cloud flying the pilot must have a sailplane of adequate strength and of suitable stability, a parachute, blind flying instruments, and experience of blind flying.

It is also necessary to be able to get out of the cloud if conditions become rough and bumpy, for it is not possible to dive out of the cloud because the sailplane, or indeed an aeroplane, cannot be made strong enough to withstand, when at high speed, the gusts that might be met. It is possible to use an effective air brake, or to spin out which is a safe manœuvre. A disadvantage of using a spin is that the pilot may want to get out of the cloud not because conditions are bad, but because he has found the blind flying too difficult and has got into a muddle. He will then almost certainly be going at high speed and so will not be able to get into the spin, which can only be started if the sailplane is going slow enough to be stalled. However, I hope it may be possible to devise a routine for getting into a spin which can be used by a pilot even when he is in a complete muddle and is going at high speed, a thing that has happened to most of us.

An attractive alternative plan is to provide an air brake so effective and strong that it can be applied by the pilot at any speed and when applied will keep the speed to a safe figure in any attitude. I think the last part of this may be easier to do than the first. It may be conveniently possible to provide an air brake that will prevent the speed exceeding a safe one without it being strong enough to be applied if the pilot has already exceeded this safe speed. It might even be possible to provide the pilot with some sort of warning, such as a whistle, which would sound at the safe speed and so warn the pilot to apply the brake before he goes any faster; if the pilot would then quickly apply the brake he would be prevented from reaching the extreme speed that the modern sailplane does reach in a dive.

One way to climb in a cloud is to circle in the best up current in the cloud. This is unnecessary and difficult. An example of this was a flight by a pilot of the British team at the International Soaring competitions this year who gained the greatest height of the day and nearly the greatest height of the meeting by flying blind and circling in a cloud continuously for an hour and a half.

Afterwards this pilot used the other method which is to " sew " the cloud as pilots now say, that is, to fly straight through it, turn in the open air, and fly back through it. Thus he gets a useful view of the cloud and the ground at intervals.

It is no part of this lecture to discuss blind flying, except that any designer will try to encourage people to practice it as much as possible before they try to fly in cloud, from a natural desire to avoid seeing the machines which he has designed descending from the cloud in parts.

There are two other problems of cloud flying that have not been provided against in any sailplane that I know of. Electric discharge and icing.

There have been instances of pilots getting mild shocks when flying, though I do not know of an example of any accident caused in this way. It seems probable that the sailplane is so small that it would have little influence on the course of a discharge and that the danger is not much greater than that of a man on the ground. At the same time it is probable that the metal parts, such as control wires, have some tendency to collect a charge and it may be desirable to bond together all the metal parts or at least all the metal parts near the pilot.

The problem of icing may have to be faced. The conditions in a cloud that has good up currents may be favourable to the formation of ice.

Of the three known methods, the new one which is being tried by Imperial Airways sounds as if it is the most suitable for sailplanes. The Goodyear method, which has rubber tubes along the leading edge, requires a supply of compressed air to be passed into the tubes at intervals to inflate them so that the ice will break off. The method that has been developed at the Royal Aircraft Establishment, of having porous tubes from which a chemical exudes, does not need so much power to drive it, but like the Goodyear method it needs a fitment along the wing which would be heavy and expensive to some extent at least, and would be difficult to make as smooth and as polished and of as low an air resistance as the ordinary varnished plywood surface.

The third method about which a little has been published, which is being tried by Imperial Airways, is to use a special chemical fluid which is smeared on the wing and which prevents the ice forming. The surface that results from this is likely to have a higher resistance than the surface without the fluid, but at least the system is easy to use. And if it is effective with the aircraft of Imperial Airways which fly at high speeds for long distances through rain and fog, it should be more effective in the less severe use on a sailplane.

THE KING KITE.

In an appendix, there is a list of the characteristics of the best contemporary sailplanes.

The quality of the structural design cannot be judged directly by the weights of the sailplanes, for their strengths vary. I believe that the sinking speeds of most or of all of the German sailplanes have been measured. The sinking speed of the King Kite has been measured roughly, that of the Hjordis has not been measured.

The needs of cloud flying have caused some evolution in the design of sailplanes between 1931 and 1937. The chief changes are an increase in strength and an increase in the stability of a sailplane to make it easier to fly blind. Also the need for a good performance has caused all cockpits to be closed with a streamline cover.

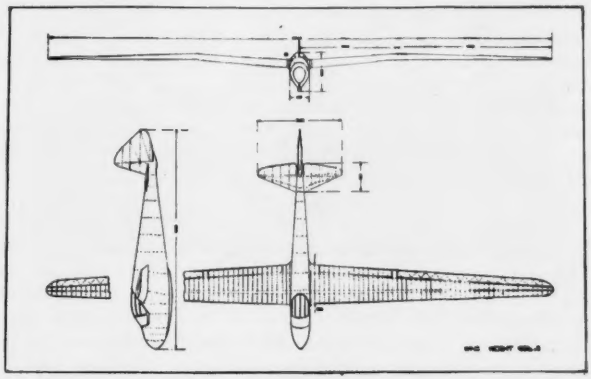

FIG. 6.
King Kite.

A British sailplane which was designed to meet the new conditions is the King Kite, three of which were built by Slingsby Sailplanes for the International competitions at the Wasserkuppe in Germany, although they were not fully developed at that time.

The sailplane has a cantilever gull wing of thick section and moderate taper.

As this sailplane was intended to have a good performance at high speed, it was thought necessary to reduce the amount of taper of the wing compared with, say, Hjordis so that less twist would be needed to avoid an increase in rolling instability near the stall, which is caused if the stall starts near the wing tips. As the twist is lessened, the distortion of the lift distribution over the span at high speeds and the corresponding increase of induced drag is minimised.

Also the strength is increased for the inverted flight condition, for a twist that gives a reduced incidence to the wing tips in normal flight gives an increased incidence when inverted and so large bending loads are caused.

The factor with c.p. forward is 8. Some German sailplanes are built with higher factors than this. A fully aerobatic aeroplane was required, a few years

ago, to have a factor of $7\frac{1}{2}$ in this condition, and a factor of eight seems to be adequate for any sailplane that is intended for soaring. It might be increased if a sailplane were built for aerobatic use; but for this there should also be other changes in the design. For the high speed condition, the stiffness of the wing is critical and this wing is limited to a fast glide at 140 m.p.h. (225 km./hr.) owing to aileron reversal.

Tests of the wing of the King Kite have just been made at the Royal Aircraft Establishment. These suggest that the speed restriction on account of aileron reversal should be to 110 m.p.h. (177 km./h.) and to 116 m.p.h. (187 km./hr.) on account of flutter.

This is a new consideration in the sailplane world and I hope that it may become possible to avoid it because the wing would otherwise, I think, be strong enough for a higher speed.

Apart from this, the general dimensions of the wing are similar to those of Hjordis. Owing to a greater structure weight, the wing loading is rather higher in spite of an increase of wing area, and this, together with the effect of a wing section of lower lift coefficient, makes the stalling speed of this machine higher. Although the performance is good when traversing down currents and travelling against the wind, the high speed is a handicap when hill soaring in a light wind or when circling in a small thermal up current. This is apparent on theoretical grounds and is confirmed by reports by pilots.

I think that the wing loading of a future design of sailplane should be somewhat reduced, although there are stronger winds in England than in Germany and as the pilot will more often want to work across wind owing to the nearness of the sea, I expect that the best sailplane for English conditions will be faster than the best one for German conditions.

The flaps were fitted for landing, to reduce the speed and increase the gliding angle when fully down, and perhaps to improve the low speed performance when slightly down. I hope it will be possible to make tests to show the effect of small flap deflections on soaring performance.

The wing section at the root is N.A.C.A. 23021 and at the tip is N.A.C.A. 4312. This is much thicker than is the latest practice in Germany where cantilever wings, whose root section has a thickness ratio of 12 per cent., are now used. Such a wing is very flexible, but no ill results have come from this as far as I know.

The merging of the body into the wing is a problem, complicated enough in itself, which is made more difficult in a machine that is built to a limited price.

Alternative courses are to have a wing that runs straight into the body without any change of section, of which the King Kite and Minimoa are instances; to have a small fillet like the Rhonsperber; or to design the wing and body together so that the wing merges smoothly into the body like the Sao Paolo. This method of making the wing grow out of the body might perhaps be called a " growth " as opposed to a fillet which always seems to be something of an afterthought.

In a bird the top and front edge of the wing run very smoothly into the body, and the undersurface of the wing runs up to the side of the body which is almost at right angles to it in front elevation. One cannot make direct comparisons with a bird as it has problems, flapping and automatic folding, which we avoid. Mr. Baynes has noticed that the trailing edge feathers by the body change their position as the speed of the bird varies, and this may be necessary to maintain a smooth air flow. This is not the sort of mechanism that would be easy to make suitable for everyday use on a sailplane.

I think that it is evident that the " growth " of the wing root of the Sao Paolo is an arrangement that exposes nearly the minimum area to skin drag, and if it is streamline, as I suppose it to be, it must be the best solution. The fact that the root fittings can be deeper and lighter is an additional advantage.

It would be interesting to know the exact form of such a growth for minimum surface area and I suggest the problem for the attention of a mathematician. The first attack on the problem is to find the growth between a parallel wing and

a body which might be taken to be of constant cross-section, whose exposed surface is a minimum. If the answer to this is a " growth " of a shape which is difficult to make, a second attack with appropriate limits to the kind of growth could be made.

For want of convenient technique for bending ply in two planes, it is only possible to make a shape such as this by fitting together a number of small pieces of ply to form a surface that approximates to the curved shape that is wanted.

For the King Kite it was not desirable to go to the expense of doing this, so that the alternatives were to have a small fillet or to have no fillet.

There is some evidence to show that if the shape of the body and the wing position are chosen correctly, the fillet is unnecessary and indeed a disadvantage. To try to make a fillet unnecessary the body of the King Kite widens slightly towards the trailing edge at the level of the wing. A small radius has also been constructed of short pieces of ply between the body and the wing (the value of this is unknown) and there is no other structure to make the flow smooth at this point.

FIG. 7.
Sao Paolo, wing-body " growth."

FIG. 8.
King Kite, showing wing root.

I do not know if the flow here is satisfactory or not, and I hope that some tests may be made to show whether this cheap and simple arrangement is a satisfactory solution of the problem.

If the wing fuselage junction is to be done like this, it is necessary, or at least very desirable, to make the fuselage with a plain cross-section at this point and large enough to contain the pilot rather than to have a smaller fuselage to contain the body of the pilot only with a streamline excrescence for his head. It is an advantage also if the main structure of the fuselage extends

above the head of the pilot to protect him if the sailplane should turn over on to its back; and the wide space for his head gives him comfortable room and also allows him to move his head to the side of the fuselage and look almost straight down when hill soaring. For these reasons the cross-section of the King Kite fuselage is a simple oval which contains the pilot.

The making of a satisfactory transparent roof is largely a matter of workshop technique and equipment, which increases with practice.

Pilots have complained often and bitterly of the smallness of cockpits of sailplanes, but with this machine I am delighted to say that I have heard only two complaints, one that it is a little larger than it need be and one that it is uncomfortably large.

I think that something has been learnt from this sailplane, and I hope that more will be learnt.

FIG. 9.
Nose of Reiher.

FURTHER DEVELOPMENTS IN ENGLAND.

The International competition at the Wasserkuppe showed that we are behind the Germans, and indeed behind the Poles and Swiss.

I suppose that our pilots need more practice and that some new system of producing new designs is needed.

For the improvement of the piloting it is necessary to have more competitions which can only go well if there is more flying of a high standard so that there will be a large number of good competitors. As more pilots become good it will be possible for clubs to run eliminating competitions among their members to select the pilots who will represent them in the club team in the annual B.G.A. competition. For this clubs will need to have a few high efficiency sailplanes for their best pilots.

I think that there is a need for a British machine of high performance and moderate price. I think it is clear that all competitions will be keener and all flying will be more interesting if a great number of machines, all nearly as efficient as the best, are flying.

The design of sailplanes in England has suffered because the market is not large enough to support a design staff and there has been no continuous development of good designs. There have been several machines which have been promising and efficient and we would be well off if improved successors to them were available to-day. For example, the Cloudcraft Phantom, the Tern, the Scud, and perhaps I may add the Hjordis and King Kite, were designed by staffs

which are not still available to work on improvements. I think that it is probable that if a standing design staff could be arranged to work continuously on the design, testing and improvement of sailplanes, the breed of sailplanes would be better than it is at present. Of course it would be better still if the industry were larger and could support the competing design staffs of several different makers. But as a first step even one man, though he might not have so much scientific and mathematical and practical ability as, say, Herr Alexander Lippisch, could make an improvement.

Another difficulty of the small production in England at present is the lack of practical information. It is possible for the designer to make a performance estimate and a weight estimate for a sailplane with the data that is available from aeroplanes. It is not possible for him to make a performance estimate with the data from British sailplanes, for I do not know of one whose performance has been tested. Still less is it possible for a costing staff to make a price estimate from the information that is available.

Of course it is possible for a manufacturer to form a rough idea from his experience of the approximate price that a sailplane to a given design will cost. But this is little help to the designer, for he needs the assistance of detailed information while he is making the design and he cannot form an opinion of the effect of the cost of an alteration that will affect many parts if the only information on the result on the cost of each part is that it will be " a bit " or " a good deal " more expensive than another.

It would be of great assistance to a design staff if even some general information could be given. For example, the cost per square metre of covering the wing with ply and with fabric, including the cost of material and labour and of finishing with dope or varnish. And the cost of spars whether strutted or cantilever, which might perhaps be found to be roughly constant if expressed as the cost per kilogramme of the finished spar. (The cost of the strut and strut fittings would have to be considered with the strutted spar). It would also be interesting to hear the comparative cost of the ribs of a tapered wing and of a wing of constant section. The great cost of main fittings might be reduced if the designer knew the cost of different operations on them. There is also likely to be a valuable simplification of the design if the designer himself has to work on it at the bench. Most of us would like to do this, but find less time for it as we grow older.

The improvement of flying that will be caused by a good design depends on the number that is built, and the number that is built depends on the price. So that it is important that a design staff should be given good information about costs.

When starting work on a new design, it is necessary to have an idea of the general lines to be followed, for it would be clearly impossible to investigate every kind of layout.

I show a general arrangement sketch of a layout that I should consider if I were able to work at the design of a high performance sailplane whose price is to be low.

It is in many ways similar to Kurt Schmidt's Atalante, a design which seems to deserve sincere flattery. The body is square in section with the wing laid on top. It could be made of wood with a fabric cover. The cabin has a roof which might be satisfactory aerodynamically and which gives the space for the head of the pilot which is liked by pilots. The tail has a fixed horizontal tailplane and there is a good fin to the rudder which seems to be desirable for the kind of stability wanted in cloud flying, and an air brake would be needed for landing and if possible to be useful also when flying in cloud. If this were not possible, the sailplane would have to be easy to spin and easy to get out of a spin and would have to be thoroughly tested for this.

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I show a tapered cantilever wing. It would be necessary to estimate the performance and cost of a strutted wing for comparison. When considering the

strutted wing, an estimate could be made of the effect of carrying the strut out from the wing and body on the end of fittings which stand out at right angles to the surface as is done in the Moazagotl.

But the proportion of successful high performance sailplanes which have cantilever wings is now so great that I should prefer to play safe and use a cantilever wing if there were doubt about the effect of a strut on performance.

I show also a general arrangement sketch of a layout for a high performance sailplane for competition. It is a development of the King Kite and is based

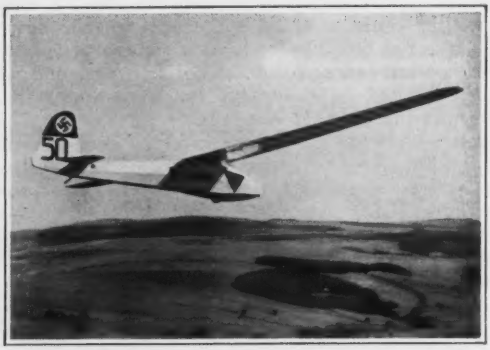


FIG. 10.
Atalante.

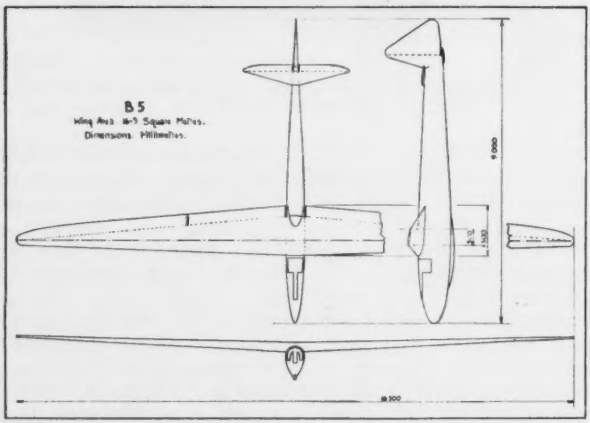


FIG. 11.
B5. A high performance project.

on the experience gained with it. The changes are that the wing has not got a bend in it so that the root is carried nearer the top of the fuselage, which, I think, would benefit the flow at the root. This change may not be necessary if the wing fuselage junction of the King Kite is shown by tests to be satisfactory.

The wing area is increased and the span is slightly increased. The wings join together so that the number of main fittings is reduced from 4 to 2. The tail

layout and the rear part of the fuselage are modified to improve its spinning qualities.

The resistance of the fuselage would be reduced considerably if it could be made as shown, like the Reiher with the windows fitted in a smooth streamline shape.

Lastly I come to the possibility of developing a new type of sailplane which will have a performance superior to anything that we have at present.

It is apparent from the success of the Austria that the greater part of the size. weight, and resistance, of the fuselage of the ordinary sailplane is unnecessary for the primary purposes of streamlining the body of the pilot and carrying the comparatively small loads which are felt by the tail when in flight.

Two ways of avoiding this are the way adopted by Dr. Kupper of carrying the tail on a boom and having a length of tail that we should consider short, and the way that has been tried successfully on several soaring sailplanes, but not yet on a high performance type, of having no tail at all.

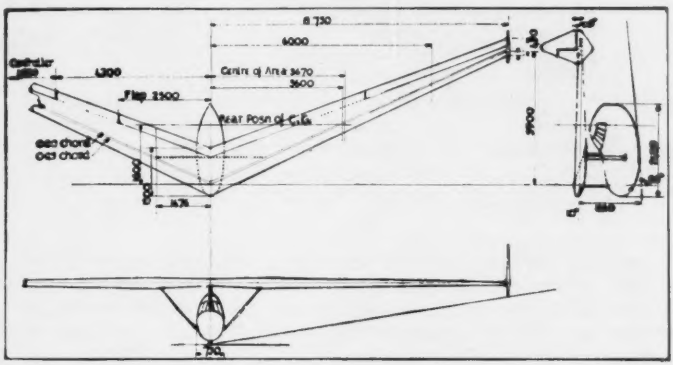


FIG. 11*a*.
A tailless project.

In a tailless type there is no doubt about the effectiveness of the rudders which are carried on the wing tips, where the drag as well as the lift has a turning effect when they are deflected.

The pitch stability of tailless aeroplanes has been somewhat wanting, particularly in damping, but it seems apparent that the great sweep back of a wing of high aspect ratio, in terms of the distance of the wing tip behind the wing root will remedy this in the case of a sailplane. Calculation and experiment seem to support this idea.

It is convenient and even necessary for the balance of a tailless sailplane for a wing section to be used whose centre of pressure is stable. The latest American section combine this valuable property with good values of lift and drag so that there is now no disadvantage in using a stable section.

The preliminary general arrangement drawing shows a layout for a tailless sailplane. The layout is necessarily unconventional, but the structure is simple. Owing to the need of a good forward view, it is not desirable to support the wing on a neck, and the strutted wing is shown. It will be seen that the struts lie in a straight line in a plan view, and there are struts in the wing taking the end load in the same straight line. Thus all the strut fittings can be flat plates as simple as those of any other strutted sailplane.

No.	Nation.		b M	S M²	W_{tot} Kg	W/S Kg/M²	W/b² Kg/M²	v_s M/sec.	ε	b²/S
1.	Poland	Orlik	14.4	14.1	233	16.5	1.13	0.7		13.6
2.		CW 5/35								
4.		PWS 101	19	19.4	265	13.6	0.73	0.61	26.1	18.6
6.	Swiss	S 18 T	13.3	13.2	185	14	1.05	0.7	20	13.5
7.		Spyr III	16	13.6	185	13.7	0.72	0.55	27	19
8.		Moswey II	13.8	12.2	200	16.4	1.05	0.68	25	15.7
10.	Czech	Tulak G.C.	16	16	275	17.2	1.07	0.7		16
12.		Duha II Mario	16	16	280	17.5	1.1	0.65	31	16
14.		VSB 35 Olomouc	18	18	270	15	0.83	0.65	28	18
15.	England	Hjordis	15.5	11.5	230	20	0.96	0.61		21
16.		King Kite	15.6	13.6	282	19	1.06	0.82	25	18
20.	Germany	Atalante	16	16.5	235	14	0.92	0.6	28	15.5
21.		Minimoa	17	19	290	15.3	1	0.65	26	15.2
22.		D Moazagotl.	20	20	270	13.5	0.67	0.58	23	20
23.		Fafnir II (Sao Paolo)	19	19	340	18	0.94	0.56	28	19
24.		Reiher								
25.	Austria	Rhonadler	17.4	17.9	240	13.4	0.79	0.60		16.9
26.		Condor II	17.2	16.2	320	19.8	1.08	0.65	26	18.4
27.		Rhonsperber	15.3	15.2	230	15.1	0.98	0.72	20	15.4

The wing is a medium thin section throughout, and is twisted to a degree that will give balance and control with very little increase of drag. There is very little increase of induced drag at high speed with a tailless aircraft because the wing moment at the root must remain constant and so the span loading can change only slightly. But there may be a considerable increase of form drag if the wing flies with big controller deflection when at high speed. This plan form was chosen to minimise the deflection and therefore the drag of the controllers.

The construction of this sailplane is fairly simple and should be cheap, and I have a hope that one day it may help many pilots to make good flights.

N.B.—I have used the metric system. I have found that it is preferred in glider works which have had to use both systems, and it is convenient for calculations. I hope it will not be found a difficulty by readers.

CONVERSION TABLE.

	For Slide Rule.	For the Head. (Error 1 %).
Metres to feet ... ... / Metres per sec. to feet per sec.	× 3.28	× 3, add 10 per cent.
Kilometres to miles ... ... / Km. per hr. to miles per hr.	× 0.621	× $\frac{5}{8}$.
Kilogrammes to pounds	× 2.21	× 2, add 10 per cent.
Kg. per square m. to lbs. per square ft. ...	× 0.205	÷ 5, subtract 2 per cent.
Metres per sec. to m.p.h.	× 2.24	× 2, add 12 per cent. (*i.e.*, add one-eighth).

For conversion back, do the opposite, *e.g.*, feet to metres, subtract 10 per cent. and divide by 3.

Discussion.

The Chairman: Those of them who had read the paper in advance knew that he had not dealt within the space of the hour with all the points that he outlined in the paper, but he had given an excellent summary of the paper and had provided a lot of material for discussion. It seemed to him that this occasion was a very important one, as through the instrumentality of the Royal Aeronautical Society the progress of the development of motorless flying could be marked in the Society's records. After all, there were in the room the leaders of the movement in the country in the scientific, technical and executive fields, and he hoped that a number of those would join the discussion which they were about to have. He (the Chairman) had a few remarks to make, but he thought it would be more appropriate to make those later; but if there was not time he would pass them over to the Secretary so that they could be printed. He would first of all call on Professor G. T. R. Hill, Professor of Engineering at the London University College, to open the discussion.

Professor G. T. R. Hill, F.R.Ae.S.: He thought they must all stand amazed at the wide range of the different qualities shown by the lecturer. As the audience knew, he was a splendid sailplane pilot and an extremely skilful designer. In addition to that, he had done valuable work in connection with gliding clubs; but that was not his main work, it was just a spare time job which he did after hours. He thought that was a very remarkable achievement for anyone who had his normal professional duties to perform.

He had been asked to open the discussion as representing the venerable pioneers of the past; he had been conjured up out of the murk of the last century, almost, to tell the audience something of what happened then, and he hoped the audience would forgive him if for a moment or two he did go back. The lecturer had talked about the materials which were now used for building gliders as having been available for several hundred years, and he thought that Squadron Leader Buxton might have gone even further back and said two or three thousand years or more. He thought that the Egyptians had all the materials of construction—perhaps he was not right in saying that they had all, but they had quite effective substitutes for the steel, for instance, which was now used, but they had not Squadron Leader Buxton to help them in those days. He, the speaker, did not go back quite as far as Egyptian times, but it was just over 25 years since he had made his first glide, and it might amuse the audience to hear for a moment how things happened in those days, so that they could compare with the great organisation which they would see if they visited Dunstable to-day.

His glider in those days ran on a rail like the Wright brothers' aeroplane did in the very early days. On the day of his first glide, he made many false starts, and eventually the darkness came on; but he still persevered, and by the time he did actually get off the ground it was quite dark. He realised that he was flying then because the screaming of the little wheels on the rail on which the glider ran had suddenly died away; he looked down and saw that it was all black below, and he had looked up and saw that it was nearly black above; there was the faint horizon of the hills opposite, so that he knew he was the right way up, but that was about all he did know. Anyhow, after about half an hour —it was probably actually only five seconds—he heard a swishing noise below, and he realised that he had made a perfect landing. He thought the audience would agree that he had had some luck with him that time.

Going back a little earlier to the days of the construction of the glider, there had been various interesting considerations which had weighed upon his mind. In the first place, he had built the glider in a room at the top of his house in Hampstead, and the maximum dimension of the chord of the wing was determined by the diagonal measurements of the window out of which it had to go. One of the things that he had discovered during construction was that the centre of gravity of the glider always used to move backwards, a common occurrence

in aeroplane design experience. He did not know whether that happened with the high organisation which prevailed to-day, but perhaps someone in the audience could enlighten him on that point. Another thing that he had been troubled with, and which he was sure Squadron Leader Buxton was not troubled with—at least, he hoped not—was that as time went on he grew older and heavier, and so the machine had to grow larger and larger; consequently the balance got upset; but as he had been only 15 years of age when he had started that design, he felt that the lecturer was not in exactly the same difficulty.

He must now cut short his reminiscences, because there were a number of people present who did know something about modern gliding and soaring, but he would like to say one or two words with reference to the problems facing the glider designer, and the parallel problems facing the aeroplane designer. He thought it was right to say that glider designers were really years before aeroplane designers in appreciating the very great importance of real smoothness on the wings; they did take very great trouble in getting a highly polished surface, and certainly in Germany they got strong young men to polish the wing surfaces before some of the long-distance flights were made. It was years after that that aeroplane designers had begun to get as excited as they now were about that very high degree of smoothness.

One of the points in the paper which had intrigued him was the question of measuring gliding angles, because these very small angles were extremely difficult to measure. To measure accurately an angle of 1 in 26 required a high degree of skill, and he would like to know how good accuracy could be obtained in making a measurement of that kind.

Another point—coming back to structural matters—was the question of stiffness in bending of the wings. It was a very curious thing that it did not seem to matter how flexible a wing was in the vertical plane; wings with low bending stiffness were possibly even safer from flutter than wings with high stiffness. Torsional stiffness was an entirely different thing, and high torsional stiffness was the great desideratum, of course, and called forth a high degree of skill from the designer of a sailplane with very long-span wings.

He thought that he ought to give place at that stage to those who could speak further on the subject and criticise from a knowledge of present-day conditions; but before he sat down he would like to say how pleased he had been to see that last slide come up on the screen, and he was sure they all hoped that that machine would actually take shape under Squadron Leader Buxton's guidance.

Mr. W. O. Manning, F.R.Ae.S.: There was one thing which had struck him about the paper particularly, and that was the generally rather vague way in which the performances of the different sailplanes had been referred to. They had heard that one machine was better than another, but they had been told that as time went on, in the last fifteen or twenty years, the performance of those machines had improved. That might be true, but he confessed that in his own mind he was not completely convinced that it was. The performance of a sailplane depended very largely on two things—the skill of the pilot and the sinking speed or the efficiency of the sailplane. Those two things, so far, had never been tested separately, so far as he knew. He thought it would be a very sound thing indeed if a sailplane of modern design could be properly tested in a wind tunnel. That would be an extremely convenient procedure, because it happened that the Reynolds number of the sailplane was fairly low, and he did not think it would be necessary to go to the expense of testing a sailplane in a compressed air tunnel. Looking at the matter generally, it did seem to him that the aspect ratio had been made rather a fetish. If the L over D were calculated for various aspect ratios while the wing area remained the same one would find after about 16 or 17 that the curve taken would flatten out. In other words, the curve generally resembled something like the sketch which he now made on the blackboard.

There was another thing that one noticed in looking at the various designs, and that was that the chord at the tip was very often very small compared with the chord at the root. One knew from experience that that sort of thing was extremely likely to produce trouble with regard to wing tip stalling, and he could quite understand with some sailplanes that trouble of that sort might quite easily happen, with a consequent loss of control; but he thought that the important thing to do for the future with sailplanes in this country was to investigate more thoroughly than had been investigated before the performance of the machine, so that this performance could be expressed by figures known to be closely accurate.

Mr. B. S. SHENSTONE, A.F.R.Ae.S.: In thinking over Squadron Leader Buxton's lecture, several things occurred to him which might be of interest to those who were keenly interested in the subject. What was of great interest was the performance of sailplanes on the skin friction basis. In connection with aeroplanes it was now common practice to compare their drags with the drag of a flat plate at the same Reynolds number in order to find some measure of their aerodynamic efficiencies. In the case of aeroplanes one must know the speed, power and the operational height, whereas for sailplanes one required the gliding angle, speed and height. Full-scale sailplane polars had been determined in the last few years by the Germans in Darmstadt by gliding the machines in the early morning when there were practically no up or down currents, and continuously recording air speed, air pressure, temperature and humidity. Those tests were carried out between 1,500 and 6,000 feet which gave opportunity for a long glide of the order of five minutes and reasonably accurate readings. He himself thought that those tests were the only type worth while. Model tests were not worth considering. Using the polar of Fafnir II and considering the operating condition as $L/D = 26$ at 40 m.p.h. indicated air speed, the efficiency on the skin friction basis comes to 85 per cent. The corresponding figure for the Heinkel 70, one of the most efficient aeroplanes, is only 64 per cent. This gave some idea of how highly developed some sailplanes were. Actually they were not so far ahead of the aeroplane as the figures just quoted would infer, as they were based on the assumption that the airflow over the sailplane was fully turbulent. Actually a large proportion of the flow over the wings of a sailplane was probably laminar. If one assumed that instead of the flow over the wing being fully turbulent, it was in a transition stage, one would probably reduce the 85 per cent. to about 75 per cent. Even this was well in advance of the aeroplane. In working out the drag coefficients, one must be sure at what height the drag was measured, because one could get different drags at different heights due to the change of the Reynolds number at constant A.S.I. He had assumed that these had been measured at ground level. If they had been measured at 10,000 feet, the efficiency figures would be increased by about 5 per cent.

He had found some evidence which showed that there might be quite a considerable amount of laminar flow over the glider wing. Before taking-off, it is the custom to wipe the dust off the wings of sailplanes, and many have wondered whether it was worth while doing so. It had occurred to him to measure the size of typical dust particles to see whether they were likely to affect the performance. With the help of a colleague, Mr. H. O. Sommer, he got a piece of glass and laid it down in a place of tumult and turbulence, an aeroplane factory in the throes of mass production. Later he had picked up the glass and found it was a mass of dust. He had blown the dust off as it would be blown off by the wind and then he had measured the size of the particles that remained, and he had found the average size to be about half a thousandth of an inch in diameter. According to Relf's formula for the maximum permissible roughness in fully turbulent flow, three thousandths of an inch diameter particles were allowable without affecting drag. But if the flow was laminar to start with, the small half thousandth inch particles would be sufficient to cause the laminar flow to break down into turbulent flow, resulting in a marked increase of drag

and reduction in performance. Accepting the evidence of pilots that dust does affect the performance, this led to the conclusion that there was considerable laminar flow over sailplane wings.

He would like to ask Squadron Leader Buxton why he used section N.A.C.A. 4312 for the tip of the King Kite wing, and why he had not used a symmetrical section such as N.A.C.A. 0009 or 0010. If one looked up the characteristics of these sections at the correct Reynolds number one found that the lift curve of the N.A.C.A. 4312 had a relatively sharp peak with considerable reduction of lift after the stall, whereas the symmetrical sections had a smooth-topped lift curve, the lift remaining practically at its maximum up to 28° incidence at an aspect ratio of 6. He was of the opinion that high tip lift was not important compared to the necessity for having a very gradual tip stall. This led directly to the question of wing dropping and the incipient spin. Surely without wing dropping a spin could not commence. He saw no reason why sailplanes should not fulfil even more stringent regulations for lateral stability near the stall than those laid down in Air Publication No. 1208, Design Leaflet F-3. Lateral stability at high incidences was vital for a sailplane, which spent so much of its flying time very close to the stall, and had to endure very high relative gust speeds. He would put forward the following suggestion for lateral stability tests as a feeler:—

The sailplane to be considered satisfactory regarding lateral stability if it could fulfil the following:—

(1) Sailplane to glide at the stall, no effort being made to control it laterally, and the control column moved slowly back to its full extent, keeping the sailplane on a straight course with the rudder. The sailplane must be laterally stable and not flick into a spin.

(2) The sailplane on a slow glide to be banked over to 30°, the control column then eased gradually back and then over to the side to unbank. The rudder not to be moved. The sailplane must not commence to spin or get into a steep spiral.

(3) The sailplane to be stalled and rudder applied. When the wing drops to 30°, opposite aileron to be applied and the rudder centralised. The sailplane must not go into a spin.

He was of the opinion that there was no point in striving after minimum wetted surface for a sailplane. It was the form and distribution of the skin that mattered more than the area. In many designs an increase of wetted surface if correctly applied would increase the performance.

He pointed out that the problem of aileron reversal is one of stiffness and not of strength as inferred in the printed lecture. If the centre of applied lift due to the movement of the aileron could be brought closer to the flexural axis of the wing, the reversal speed would increase. Thus it might be worth while to increase the aileron chord. If the aileron could be so proportioned that the centre of applied lift lay on or in front of the wing flexural axis, there would be no aileron reversal speed.

It appeared to him (the speaker) that the most difficult thing in the stressing of a sailplane—and Squadron Leader Buxton had experienced it himself in designing sailplanes—was to know what gust speed to take. He suggested that there was much work to be done in measuring gust speeds, particularly in clouds. An aeroplane would probably avoid clouds when possible, but as they are the life of a sailplane flight, they must be entered or the flight given up.

He pointed out that in the Standard Glossary of Aeronautical Terms, the word "sailplane" did not occur. Perhaps there was no room for it in a book so overfilled with curious words, but he felt that there could be no objection to dropping the word "aerodyne" which nobody used, and letting in the word "sailplane."

There is very little information available on the effect of ailerons on the stalling characteristics of symmetrical sections at the Reynolds numbers occurring at the tips of sailplane wings. What little information that is known to the writer indicates that the stall is not made noticeably sharper by the deflection of the aileron.

Professor D. BRUNT: As Chairman of the Council of the British Gliding Association, he felt sure that all the members were very much indebted to Squadron Leader Buxton for his very interesting lecture, and especially to the Royal Aeronautical Society for giving them an opportunity of hearing the lecture. At the same time, he was very pleased to think that the Chairman of the meeting was also President of the British Gliding Association.

He himself had come into the gliding movement as a meteorologist, but he would refrain from talking to the meeting about meteorology because to that subject there was no end. He thought that the salient points had been summarised very clearly and accurately in the paper.

There was only one thing that he did wish to comment on, and that was the reference to the participation of a British team this year in the international competition at the Wasserkuppe. The conclusions drawn by Squadron Leader Buxton were that the competition showed that the British were behind the Germans, and, indeed, behind the Poles and the Swiss. He would agree with that—that the British were behind them to some extent in design, and to a greater extent, not in skill of pilotage, but in experience. That experience was only to be gained, in his view, by their taking part in more competitions. During a competition a pilot might set out in conditions which appeared completely hopeless, only to find that, instead of coming down (say) 10 kilometres away, he achieved a flight of 160 kilometres. The psychological effect of such a happening must be tremendous. Something of this kind happened one day during the competitions at the Wasserkuppe, when Dittmar, the only pilot who succeeded in getting away from the neighbourhood of the hill, achieved a flight of 177 kilometres. He thought the only way to increase the efficiency of British pilots was by having more competitions, because they would in that way force their pilots to go out in conditions in which otherwise they would not start. Some care was necessary in comparing the performances of pilots in this country with those on the Continent. One had to remember that, after all, England was a very small place. Starting from Dunstable, 104 or 105 miles was the absolute maximum that one could achieve in an easterly or north-easterly direction, whereas if one started from the Wasserkuppe it did not matter what the wind direction was; to all intents and purposes one had the wide world before one.

He hoped that in the not too distant future the gliding movement in this country would be able to supply them with further information as to what happened in the atmosphere. He did not for a moment imagine that they would find in the atmosphere thermals exactly like those produced in the laboratory; there must be differences; but, at any rate, the laboratory thermal was a model which could be used as a standard for comparison. It was within the power of the gliding movement to make a very real contribution to the knowledge of convective motions in the atmosphere.

Herr KRONFELD: He had been supposed to fly one of the best modern owner's aeroplanes recently to Switzerland, but he had postponed his flight for two reasons; first of all, he wanted to listen to Squadron Leader Buxton's lecture, and, secondly, he had thought what might happen if the engine had cut out.

He had always been extremely interested in the limits of development of the gliding movement. He himself had had certain experiences, as the audience had seen when a certain slide had been shown. The reason was that it unfortunately took a very considerable time to design a glider which differed so much from any glider designed before. The Austria I had been designed by Dr. Kupper, a most brilliant designer, who unfortunately had died that year. He had designed a machine in 1928 and 1929, but the first time he had been able to fly the machine

successfully was, he believed, in 1931. By that time the gliding movement had made such progress that machines were able to fly regularly in thunderstorms, and to fly for hours, and that had become quite a normal thing. In flying competitions a pilot always took greater risks. He himself had done something which he should not have done, and that had been to fly a machine into cumulus cloud. There were two things which were interesting; one was that he had been the only one to reach that cloud on that particular day from Wasserkuppe in spite of the efforts of other pilots to get there. The Austria I had a gliding angle of well over 1 in 30, compared with other machines with a gliding angle of 1 in 20 or 1 in 22, and a sinking speed twice as high. That one pilot had been able to fly straight without spending much time in the up currents was a typical example of what could be done provided the glider adopted the right tactics. He personally did not see how one could avoid increasing the span of gliders; he had had several discussions at the London Gliding Club about that problem. He had seen designs of gliders of 16 metres, and he thought that a few years ago everyone would have said that anything very much bigger than a grown-up baby was not any use. He agreed that financially it was very difficult to increase the span. He had spent nearly £3,000 on the development of the Austria I, and if the development of the gliding movement progressed in such a way that such machines would be necessary, then it would be very difficult to make it a really popular pastime; so that something should be done to avoid that, perhaps by the creating of a class of machine of about 15 to 20 metres, and so on, so that there was really a fair comparison between the performances of pilots. But, even so, he thought it would be most interesting to try to design machines which really got to a sinking speed of something like 30 centimetres a second, for in that case he was convinced that on seventy days out of one hundred one could fly any glider at any time between 10 o'clock in the morning and six o'clock in the evening in summer time. Dr. Kupper, after having had experience of the Austria I, had said that the pilot who flew that machine was extremely silly, and that happened if one gave a pilot a machine which he was not able to fly. There was another machine which had been called the KU. 7, which had about a 20-metres span, with which one could get very nearly the same performance as with the Austria I. That machine was totally different, but several points which had been mentioned in the discussion were considered in regard to that particular machine. By decreasing the surface of the fuselage as much as possible—which was part of the reason for the famous shape of the Austria I—it was possible to decrease considerably the total fuselage by giving it that shape; but the most important thing was to take, first of all, the wing sections with practically no movement of the centre of pressure, and then to divide the wing of the 20 metres span into three parts; the centre part of 6 metres, and then two of 7 metres; and one made the aileron to move the whole upper part of the wing, mount an axis on the main spar, and thereby one could get rid of many difficulties connected with the normal type of machine. One difficulty was to get rid of the resistance given by the hinge arrangement. Both outer wings could be turned upwards; therefore the load distribution over the whole wing was dealt with in a way which made the C.P. forward much easier to handle, and in addition to that there was a simple arrangement of air brake—it was not really an air brake; it was a gliding sinking speed spoiler.

Dr. Kupper had gone about the problem in a totally different way; he had said that the landing speed of a glider was so ridiculously low that it would not matter if this were increased slightly. What was wanted was a steep approach to be able to get out of a cloud or thunderstorm, perhaps, and Dr. Kupper had got those two things by turning up the trailing edge of the machine, of the outer wing first of all, to get a better load distribution for his strength calculation, and he could increase the sinking speed practically to any extent and bring the machine down to the ground like an aeroplane with a comparatively high sinking speed. The arrangement of the tail plane high up made

landing with that particular machine possible at a speed which was not possible normally on any high performance sailplane without creeping along with the tail on the ground and then letting the whole front part of the machine, including all the expensive instruments, bump down hard on the ground. The safe flying speed of that particular machine designed by Dr. Kupper was 150 miles an hour (241 km./hr.) and it had a 20-metres span. The weight of the frame only was 129 kilogrammes, and Dr. Kupper had allowed 4 kilogrammes for the instruments, therefore giving a tare weight of 133 kilogrammes. Finally, the machine was slightly heavier, but not more than about 4 per cent., and the performance had been nearly as good as the performance of the Austria I. He had flown that machine on several occasions, but unfortunately he had not had the time and the opportunity of flying it during the competition. It had been specially designed to prove the theory of the high wing span when compared with a machine with a small wing span.

Then there had been another machine produced by the Darmstadt Flying Group with a 12-metres span. Both machines had been equally expensive to produce. The reason for the small wing span was the theory that it should be possible to stay inside a circle each side of a thermal current. It had also been proved that it paid to have a machine which could only fly straight, but the speed range was so great that one could fly very slowly in the up currents and pass through the down currents. No one had said that it was necessary to stay all the time in the up currents; one could circle through the air currents provided the speed was high enough to make proper use of it. In addition to that, one had the advantage of being able to fly straight in front of a thunderstorm, and that particular machine had been constructed in such a way as to have a speed of about 70 miles an hour (113 km./hr.), with a gliding angle of 1 in 20.

Then another machine had been designed, with the co-operation of Dr. Kupper, and that was a glider called Austria III, which only a few weeks ago was bought by a Belgian company after careful consideration of what they could get on the market, including the best German machines. The idea had been to create a machine which would serve every purpose. He had flown that machine over 10,000 miles, with luggage on board, and with that machine one could do inverted flying and, more or less, practically every aerobatic movement, and in addition to that it was first class for thermal soaring in light up currents. The wing was divided into four parts; its span was 14 metres, and the whole span was 22 metres. It had given a performance as good as any machine with a span of 40 metres. He himself had been able to get up to a height of 6,000 feet.

When flying that machine with a small wing and one man on board, the factor for C.P. forward was 14; with two people on board it was about 11½. With the big span, with two people on board, it was 7, and with one man on board it was about 9. There were two machines of that type flying at present, one in France and one in Belgium. He thought that if more of that type were built, high performance gliding would be more and more expensive until gliding became so expensive that one could not go on with it.

Mr. P. A. WILLS: He had probably the least technical brain in the room, and he would not try to pretend anything else, but there were two points in Squadron Leader Buxton's lecture which he would like to ask him about. Squadron Leader Buxton had stated that the British proved inferior to the Germans, the Poles, and the Swiss at Wasserkuppe, but as regards the Swiss he thought, apart from one rather exceptional pilot which Switzerland had produced, who he thought had been trained in Germany, the superiority which they showed was perhaps due to the fact that they produced a bunch of sailplanes which were very much lighter than anything the British had, and he thought had a very much smaller safety factor consequently. It did seem to him that perhaps the improvement in materials, and so forth, which had taken place in the past few years had not been used by designers to give them better machines, but to give them stronger ones, and really the ordinary machines which were now sold in large quantities

were quite absurdly strong for the majority of people who did not want to go breaking their necks in the clouds. He wondered whether it would be a good thing to turn out some competition machines with a factor of (say) 5 or 6, which might probably have a very much better performance than the machines which they now had, and which, of course, one would not want to push up into the clouds. He would like to ask Squadron Leader Buxton what happened when one got into a mess in a cloud in what he thought was the third most likely way; the first was the high-speed spiral dive, the second was in bits, and the third was to come out of it upside down, not neatly, but all anyhow with a wing down. There were two obvious things that one could do; one was to half roll out, and the other (he supposed) was to complete the sort of bungled loop; but he had heard of instances in which machines had broken up doing both those things.

Mr. L. E. Baynes: It had been very kind of the lecturer to refer to his (the speaker's) earlier efforts in the ancient history part of his paper, and he was sorry he had been unable to contribute anything much since, as most of his time had been taken up in trying to reduce his own sinking speed. Up to now it seemed that the main aim in the design of sailplanes had been to reduce the sinking speed to an absolute minimum, and that had largely been obtained by the expedient of providing the maximum possible span for a given weight in order to reduce the induced drag to a minimum; but now they seemed to be approaching a phase where greater flying speed range was required without affecting the sinking speed. He had been told that it would be a great advantage if one could fly at two or three times present speeds without an appreciable increase in the sinking speed, because that would permit of cross-country flights against high winds and flights from one favourable region to another with minimum loss of height. It followed that if one flew at (say) twice the present best speed, the sinking speed would be increased in that ratio, assuming constant L/D. Unfortunately the L/D ratio or gliding angle was not constant being affected seriously, so that at twice normal flying speed one's sinking speed was four to five times as great. That was due to the parasite and profile drag increasing as V^2 and so causing the total drag to be greater in spite of the reduction in induced drag, and whereas the parasite drag was only approx. 25 per cent. of the total at the speeds that one now flew at, it changed places with induced drag and became a very much greater percentage of the total and therefore of greater importance at the high speeds now required.

The part of Squadron Leader Buxton's paper which interested him most, therefore, was the part dealing with body shape and interference between wing and body, which would come under the heading of parasite drag. He thought that they must attack parasite drag and try and deal with body shape and body wing interference in a more rational way. If, for instance, they could eliminate parasite and interference drag altogether and have just a plain wing, the speed of least resistance would occur at the higher speeds which they now wish to fly at instead of at a speed only a few m.p.h. above stalling speed as at present. They would then obtain a practically constant sinking speed over a wide range of flying speeds, which is what they wanted. A lot of people had talked about a flying wing, but he did not feel that that conception was the right one to aim at. It was no use having wings flying about that one could not put anything into. One did not see birds flying about looking like plaice or soles; birds had quite fat bodies in which they carry their fuel and themselves. Therefore he felt that the thing to aim at was rather a flying body, and by a flying body he meant a body which was evolved out of the wing in such a way that it did not affect the lift distribution and was all part of the wing system. He would suggest that that aim could be achieved by considering a wing at the centre line as being increased in chord, and therefore depth, and at the same time the incidence of that bit of the wing should be successively reduced in proportion to the increase in the chord to the extent required to maintain an undisturbed lift distribution curve. He thought that they should consider the whole machine when calculating

the aspect ratio of the whole machine, *i.e.*, the aspect ratio would be proportional to span^2 over area of body plus area of wing. The body drag would therefore be, assuming it was the ideal shape and purely skin friction, virtually part of the profile drag of the wing, and, as the wing area and profile drag would be reduced by a reduction in chord to an extent equal to the area of the body, the total drag would be the same as a plain wing; in fact, one could almost say that one would then have eliminated parasite drag except for the tail surfaces and an efficiency similar to that of a plain wing would be obtained.

Mr. A. G. PUGSLEY, A.F.R.Ae.S.: The only comments he had to make referred to Squadron Leader Buxton's remarks with regard to the wing stiffness tests on his King Kite. He (the speaker) was surprised that the King Kite's properties from the point of view of wing flutter were so similar to those of an ordinary wing. Its wing density was comparable with that of a high speed fighter, and its flexural and inertia axes were disposed as in an ordinary aeroplane wing. He had wondered, when seeing the slides, whether the gap between the wing axes of the King Kite were unnecessarily large; in some of the German designs shown the weight of the wings seemed to be further forward, so that the wings really began to look like those of a bird, which were effectively almost mass balanced because their structure weight was so well forward.

The low flexural stiffnesses of sailplane wings had been mentioned, and on that point he thought that the wings of the King Kite and other sailplanes had from the flutter standpoint an appreciable advantage over most aeroplane wings. He wondered whether Squadron Leader Buxton could comment on the positions of the wing axes of the King Kite as compared with those of the German sailplanes.

Professor HILL (*who had taken the chair*): He was sorry that Lord Sempill had been called away by an urgent message, but he thought there was no need for him to compliment the lecturer further; the audience by its keen discussion had done that in the most effective way possible. It was disappointing that the discussion could not have gone on longer, because it was an extraordinarily good and keen one, but those of the audience who were prevented by shortness of time from being able to speak would have a partial remedy by putting their remarks in writing. He had had an opportunity earlier in the evening of thanking the lecturer, and he therefore declared the meeting at an end.

Lord SEMPILL (*contributed*): The following particulars may be of interest:—

SAILPLANE CONSTRUCTIONS.

DR. KUPPER KU. 4, CALLED AUSTRIA I.

This sailplane was intended for thermal and cloud flying for long distances (not for hill flying) if possible in a straight line without turning or circling round. The main features were the ailerons over the whole span, particularly for changing the curvature of the aerofoil to suit the flying conditions. Each side in three parts with different differentials for each flap. Best sinking speed 0.48 m./sec. at approximately 48 to 50 km. per hour. Gliding angle 1 in 32 to 33.

Ku. 7: Span 20 metres. Wing area about 14.5 sq. metres. Tare weight, 126 kg. Wing loading, 14 kg. per sq. metre. Aerofoils developed from N.A.C.A. This glider has a minimum sinking speed and best gliding angle at high speeds to increase the average cruising speed and to reduce the time for crossing areas of down currents.

Main Features.—Minimum fuselage drag, fuselage having a shape like Austria I, but considerably smaller in size.

No aileron or flaps, outer wing hinged.

Ku. 4 was perhaps the first aircraft to have plywood skin with grain laid diagonally.

One of the most successful competition sailplanes for thermal soaring.

Span, 12 metres. Wing area, 11.4 sq. metres. Tare weight, 45-55.5 kg. All-up weight, 136 kg. Sinking speed, 0.55 m./sec. Gliding angle, 1 in 23. Ailerons over the whole span, also to be used as flaps. Turning time, by 25°, 9 to 11 secs. at 47 km. per hour = approx. 40 metres diameter.

The Austria I was a remarkably efficient sailplane, but was not designed as a commercial proposition.

The Windspiel, also a very successful sailplane, is very expensive and difficult to build and to maintain.

The Ku. 7 was the most promising sailplane, but unfortunately has crashed after some minor flights.

The problem, for distance flying, is to design a sailplane with:—

(*a*) Best gliding angle at high speeds, which can be done by using a high aspect ratio, high wing loading, and a fuselage and tail of low drag.

(*b*) Low sinking speed at slow speeds with good flying characteristics.

PERFORMANCE FIGURES OF OTHER SUCCESSFUL SAILPLANES.

	Grunau Baby II.	Rhon-Bussard.
Span	13.5 m.	14.3 m.
Wing area	14.2 sq. m.	14.0 sq. m.
Tare weight	112 kg.	130 kg.
All-up weight	190 kg.	210 kg.
Aspect ratio	12.8	14.6
Factor of strength	8	9 approx.

Take-off Methods.—England has not many suitable hills (like Germany) for cheap hill soaring and one has to concentrate more on winch towing and aeroplane towing.

Both methods are safe and winch towing is not expensive. This method will best be done by using two-seater gliders and will greatly reduce trouble and risks.

Since 1933 Kronfeld and others have found the requirements for safety. Undercarriages should be made to drop automatically or be part of the sailplane to avoid possible accidents to spectators,

A cheap two-seater is needed for teaching.

Aeroplane Towing.—For instruction purposes it is advisable to have some shock absorber especially when using high tensile cable. Herr Kronfeld used an inset of approx. 3ft. of rubber-chord.

Some pilots, including Herr Hirth, use heavy steel cable and so get a deep sag in it which damps the shocks.

A mechanical shock absorber might be used.

One knows a great deal about currents in open country, but less of thermal conditions over hill districts (like the Alps) where large up currents develop on the hill-side at sunset, and less still regarding night soaring possibilities.

Mr. A. R. WEYL, A.F.R.Ae.S. (*contributed*): He must apologise for taking part in this discussion because his own "soaring experience" is restricted to bumping along the sky aided by an engine and to series of hurtling-downs behind a dead engine while cursing engine manufacturers and other people concerned.

As sailplanes have to be constructed in a proper manner, with proper workmanship and proper materials, and as the market is rather restricted, and the prices obtainable far too low down to allow for even a very modest profit, he failed to see any real success for the manufacturers of sailplanes over here. There is no such thing as a cheap high performance sailplane. Not only the lecturer may have designs for high performance sailplanes in mind, but as nobody is willing to pay £300 or anything like that for a sound high performance sailplane, and

as there is no hope for a production in profitable quantities, most designs will remain on paper only.

He had investigated the problem of labour saving and production costs for sailplane manufacture, and he found that if one pays decent wages and is not running a shop full of boys, apprentices or students, an average sailplane is bound to cost as much as a power plane of equal span minus the costs involved for the power plant and the undercarriage.

As to the problems of production costs Squadron Leader Buxton has raised, he might say that generally with sailplanes the number of fittings required can give a reliable hint as to expense. A cantilever wing is always cheaper, and the difference between a tapered and a non-tapered wing is small, except in the case —which unfortunately only too often is experienced in sailplane manufacture— that only one or two planes are built. Even the plank spar is not so much cheaper in comparison with the built-up spar as most people are inclined to assume. Round fuselages, struts, fillets, and fairings are usually more expensive than one would think. Even bracing by cables is expensive.

The price is commonly related to the span, but there is a lower limit, small sailplanes (not gliders) involving more working hours due to inaccessibility. Plywood covering is usually much cheaper than fabric covering, but the question of weight and accessibility have to be considered in every case. The weight problem governs the choice between a cantilever and a strutted wing structure.

Structurally the main problem with sailplane wings and especially with cantilever wings is to obtain a reasonable stiffness. Most sailplanes suffer more or less from insufficient torsional stiffness resulting in a sluggish aileron control. Some sailplanes even suffer badly from elastic bending deformations near the tip, and then the unfortunate designer is told about heaviness in the aileron control. Certain otherwise effective aerofoil sections may add to these structural defaults.

He visualised refinements in sailplane structures which may solve these problems in a satisfactory manner as to structural weight, but not yet as to manufacturing costs.

Squadron Leader Buxton has chosen for his remarkable King Kite sailplane one of the N.A.C.A. high performance aerofoil sections whose camber is low with its position of maximum camber rather forward. He failed to see the reason, and he was in agreement with Wolf Hirth, the famous pilot and designer, in preferring the type of aerofoil sections hitherto in common use for sailplanes.

Consideration of the scale effect should convince Squadron Leader Buxton that his bi-convex sections with their low Reynolds numbers at the laminar separation point have a high critical Reynolds number. Now the effective Reynolds numbers for sailplanes are rather low, for the King Kite approximately between 900,000 and 2,400,000. N.A.C.A. tests show a resulting loss in maximum lift (with and without flaps) and an increase in profile drag, so that there is a deterioration of the gliding angle and probably there is a limit to the optimum obtainable sinking speed as well as to the manœuvrability. The actual inferiority of the sections chosen by Squadron Leader Buxton is even more evident if it is realised that the N.A.C.A. tests in the variable density tunnel are done in the fairly high degree of turbulence which occurs in this kind of wind tunnel, and that thick aerofoil sections are more sensitive to turbulence than thin ones.

All successful sailplanes are based on fairly highly cambered sections having the maximum camber more back than 30 per cent. of the chord. He agreed that the C.P. travel is pronounced with these sections, but especially with the small chords used in high performance sailplanes the effect does not seem to matter.

Another very essential point in favour of the commonly used highly cambered sections is the shape of the lift incidence curve near the stall. Now perfect flying qualities at high incidences near the stall are especially required for sailplanes, for hill-top soaring as well as for thermal soaring. Observations seem to show that successful sailplane pilots are circling in somewhat curious looking tight turns with not much banking, while flying at the slowest possible speed. They

do it, he understood, in order not to lose the range of the lifting current. Mr. Kronfeld should be able to give more information on this point. Anyway, it is obvious that pronounced rolling instability, perhaps with ineffective aileron control, will be most harmful under these conditions.

In order to obtain the minimum sinking speed the optimum value of $(C_L/C_D)^{1.5}$ has to be reached. The angle of incidence related to this optimum is usually not much below—in certain cases even at—the stalling angle. This again means flying near the stall. The optimum gliding angle is generally related to a much higher gliding speed.

As Squadron Leader Buxton was mentioning unpleasant spinning tendencies of his sailplane, he would like to know if these tendencies have been observed while using the split flaps or not. American tests suggest a pronounced front stall at low Reynolds numbers with the bi-convex sections used on his Kirby Kite, especially with split flaps.

Another point worth while mentioning is the fact that bi-convex aerofoil sections necessitate a somewhat different shape of the sailplane, as the C.G. has to be shifted more forward than with the normally used type of sailplane aerofoils. To the writer this seems to be the trouble with the stated spinning tendencies of the Kirby Kite, perhaps in collaboration with the shape of the front part of the fuselage. He would like to know Squadron Leader Buxton's opinion about this point.

Incidentally, Squadron Leader Buxton has used near the wing tip of his sailplane an aerofoil section having an increased camber. He had tried the same on a little power plane, and he found it to give an excellent controllability in partly stalled conditions, the ailerons remaining unstalled. He was somewhat surprised that the lecturer apparently had obtained much less satisfactory results.

In one point he would like to complete Squadron Leader Buxton's survey, that is in mentioning another living successful designer of British sailplanes, Mr. Manuel, whose Wren and Kestrel sailplanes are flown in England as well as abroad.

Mr. S. Scott Hall, A.F.R.Ae.S. (*contributed*): There is little doubt that soaring as a sport is unrivalled. There is also little doubt that its fascination as a branch of aeronautics is due in no small measure to the fact that it is of no earthly use. The word earthly is used here in its strict or commercial sense. But whilst this automatically keeps it unsullied by monetary considerations, it also leaves its development in a peculiarly precarious condition. Certain countries have thought it worth while to foster it and have lent official support. They see, presumably, possibilities in soaring from the point of view of training pilots for war purposes. In these countries the organisation of the gliding movement and the funds available for experimental and design work are such that development can proceed steadily and no fears for the future can be foreseen.

Whilst this organisation provides for the future of gliding it would appear to have some disadvantages and he would like to challenge the lecturer's emphasis on the point that it has not in any way spoiled the sport. He thought that from the British view of sport the intense official boosting that is applied elsewhere and the forms which this takes have grave objections. How would they in England like having to wear uniforms when they go to Dunstable and how would they like to be marched to lunch and marched back again?

But returning to their own problem, how can one ensure that the technical development of gliding goes ahead? The lecturer has indicated that he does not regard the present situation as being satisfactory. He states that the market is not large enough to support a design staff nor to provide funds for experimental work, without which there can be little advance. What then is the solution? One possibility would be to gain the sympathetic interest of one or more of the Universities. At least two Universities—he believed—had their own gliding clubs, so that the practical interest already exists. At these Universities there are courses of study in aeronautical engineering. Surely the design and con-

struction of a sailplane would be a most useful exercise and could be done on much the same lines as those adopted by the de Havilland aeronautical school in the case of certain light aeroplanes it has produced. The machine, when built, could be handed over to the gliding club, which with the co-operation of the designers could put it through any tests thought desirable, thus ensuring the collection of scientific data. Expense is a stumbling block and he had no accurate idea of the cost of the scheme he suggested. It would not appear, however, to be unduly expensive. He would like Squadron Leader Buxton's comments on this and his suggestions as to any alternative.

On the purely technical aspects of the paper, and in connection with the streamlining of the pilot's head, surely it is far better (provided reasonable view can be given) to enclose the pilot entirely within the truly streamline shaped fuselage rather than to put his head into an excrescence built out from and spoiling a streamline shape. He always understood that the early difficulties with Fafnir I were due to the latter solution being adopted first. Numerous later designs have, however, of course, used this arrangement without any apparent loss in performance or control power.

Can Squadron Leader Buxton say anything about recent gliding developments in Russia? What aircraft are they using? Again, gliding was started with great enthusiasm in America. What has happened to development there?

Do meteorological conditions offer any possibilities of soaring at night? If they do it would seem that range might be considerably extended by the provision of suitable equipment.

Mr. ALEXANDER LIPPISCH (*communicated*): If he took part in the discussion he did so mainly regarding a number of special questions connected with his own paper read before the R.Ae.S. in 1931* and to recent progress in the development of sailplanes.

At the beginning of the development of soaring, in the years from 1921 to 1923, designers were very much occupied with the problem of dynamic soaring. Only by the success of thermal soaring were the real sources of soaring over flat country revealed, which, by some investigators, had been interpreted as the so-called dynamic effect in the observation of bird flight. The easy soaring flight of birds in regions where no mountain up currents could be present could not be explained otherwise and the theory of dynamic soaring was built up to give an explanation. To-day they knew that the up currents of the atmosphere are much more frequent and that the bird is capable of making use of these up currents due to his low sinking speed and high manœuvrability.

With a certain justification soaring flight and specially distance soaring over plain country could be called dynamic soaring if only a different scale is introduced for the order of magnitude of the regions of up currents and down currents that are present in the atmosphere. While the original theory of dynamic soaring considered short fluctuations of vertical velocity and by them explained the propulsive effect which was first developed by Knoller and Betz† one is in reality concerned with much greater fluctuations in the atmosphere. But the method of flying through these regions of alternating up and down currents without losing height remained in fact the same as the prescription of the Knoller-Betz effect, *i.e.*, to fly through the up currents at low speeds and through the down currents at high speeds. They could therefore call this practice dynamic soaring with exploitation of the macro-turbulence of the atmosphere.

Whether it will be possible in the course of later development to transform the energy of the micro-turbulence of the atmosphere into soaring energy seems at least doubtful. Compared to the sailplane the manœuvrability of the bird is so superior, that the bird can exploit fluctuations of force and direction of the wind, which could never be made available to a full-scale sailplane.

* A. Lippisch. The Development, Design and Construction of Gliders and Sailplanes. Journal of the Royal Aeronautical Society, July, 1931.

† Betz. Ein Beitrag zur Erklärung des Segelflugs. Z.F.M., 1912.

Dynamic soaring in the friction layer over the ground and at the water surface has also been observed by a number of investigators. From his own observations of the flight of the albatross, Professor Prandtl, Göttingen, himself deduced the theoretical basis for this possibility of soaring.*

Prandtl comes to the conclusion that a sailplane capable of exploiting those energies must possess a very good gliding angle, high wing loading and maximum manœuvrability. It is interesting to note that during recent years the development of sailplanes has followed this trend.

This development proceeded from the sailplane for hill soaring with lowest sinking speed to the sailplane for distance soaring with best gliding angle.

The development of sailplanes with lowest sinking speed starts with the Vampyr as prototype and ends with the Wien and the Austria.

The design of these sailplanes was based on the considerations he explained in his lecture to the R.Ae.S. in 1931. He must contradict Mr. Buxton in so far as this is not really " the last word on all it deals with." Experience from distance soaring with exploitation of thermal up currents, which include the up currents under clouds as well, showed very clearly that it is not essential to build a sailplane with absolute minimum sinking speed, but that it is much more important to reach a low mean value for the sinking speed within the range of velocities corresponding to normal flying conditions, *i.e.*, to obtain the best mean value for the gliding angle within this range. The considerations on which the recent development of sailplanes is based were laid down in his paper, " Einfluss der aerodynamischen Gestaltung auf die Leistung von Segelflugzeugen."†

He started from the diagram of velocities‡ and determined in which way this diagram is influenced by the different design factors. It then follows that to design a really efficient distance sailplane, the velocity range of which can be assumed at 60 to 100 km./h., high wing loading in combination with a high aspect ratio is required.

As a first approximation he could give the following relation between the wing loading, the mean sinking speed and the aspect ratio at a given velocity range:—

$$W/S = v_{zm} \cdot A \{ \rho/[2/\pi (1+\delta)] \} \cdot \{ \Delta v/2 \log_e [(2 v_m + \Delta v)/(2 v_m - \Delta v)] \} .$$

For fundamental considerations on the velocity range the absolute diagram of velocities is used. This diagram is obtained from the polar curves by substituting

$$1/{c_L}^{0.5} = x \text{ exact form } c_L/{c_r}^{1.5}$$
$$c_D/{c_L}^{1.5} = y \qquad c_D/{c_r}^{1.5}$$

The absolute velocity polar curve then has the form

$$y = \{ (1+\delta)/\pi A \} (1/x) + c_{Dpr} x^3 + c_{Dpar} x^3 .$$

Instead of the sinking speed we have y and for the horizontal speed x. If the sinking speed is to reach the lowest possible value between the limits x_1 and x_2 we must see that

$$y_m = \{ 1/(x_2 - x_1) \} \int_{x_1}^{x_2} y \, . \, dx = \min.$$

The numerical solution of this relation is relatively simple as the integration can be carried through separately for the profile drag, the parasite drag and the induced drag, so that systematic profile tests as are available to-day in great number can be analysed with general validity.

There is no need to go more deeply into these special questions of aerodynamic design and he had only pointed out this problem to show that since 1931 new thoughts have furthered the development and that they were far from reaching

* Uber den dynamischen Segelflug gewisser Seevögel nebst Folgerungen für den menschlichen Segelflug. L. Prandtl, Istustagung, Gersfeld, 1933.

† Luftfahrtforschung Bd. 11, Nr. 5, 1934.

‡ Journ. of the Roy. Aer. Soc., 1931, p. 557, Fig. 21.

the end of this progress. A consideration of the methods of construction that are able to be realised shows that in the present state of knowledge it must be possible to reach L/D ratios of 1 : 40.

The development that aimed at obtaining the absolute minimum of sinking speed necessarily had to lead to very different opinions regarding the residual drag, as for the attainment of a relatively high value of c_L^3/c_D^2 the cutting down of drag is less important than the increase of maximum lift. To reach the best gliding ratio c_L/c_D only the absolute minimum drag is of decisive importance, specially when this best value is to be reached at low lift coefficients, *i.e.*, at high velocities.

To reach a minimum sinking speed it was therefore correct to build the Wien in the form of a strutted high wing monoplane, while in modern constructions, as for instance the Reiher, the aerofoil thickness is reduced regardless of the structure weight of a thin cantilever wing.

The transition from the strutted or cantilever high wing monoplane to the mid-wing monoplane was only possible by adopting the closed cockpit. When using an open cockpit the flow over the mid-wing portion is so violently disturbed, that the advantages of this method of construction are not realised. The closed cockpit had further to be adopted as cloud and front soaring leads through rain and hail regions where flight cannot be carried on without proper protection. Quite different considerations therefore lead to the same conclusions and the best sailplane is therefore determined as a mid-wing or semi-high wing monoplane with closed cockpit.

The problem of wing fuselage combination had also to be solved. Older tests showed that with the mid-wing combination stalling takes place in the expanding passage formed by the upper wing surface and the fuselage wall and exerts an unfavourable influence on the upper part of the polar curve. The important tests by H. Muttray have definitely solved this question.*

Muttray proved that the smooth merging of the wing into the fuselage leads to a considerable decrease of total drag if the distribution of profile form and of incidence is such that the lift distribution of the wing without fuselage is maintained.

The high performances that were reached with the Fafnir II " Sao Paolo " proved the truth of these conclusions. It must, however, be kept in mind that there is a fundamental difference between the fillets and the " growth." The fillets serve to reduce the effect of the expanding passage, while the " growth " combines wing and fuselage to a single lift-producing system. The fuselage now forms part of the aerofoil and produces the lift that is aerodynamically required in this region. By including the fuselage into the aerofoil one cuts out its parasite drag, as the body drag turns into profile drag and can be entered into the assets of the performance balance.

To carry out such designs it is, however, indispensable to have a sound knowledge on the aerodynamic fundamentals of the design of aerofoil sections and of plan forms. It was a great pleasure for him to say that Glauert's work proved a most valuable help to them on the way to reach this aim. The theory of aerofoil sections following Birnbaum-Glauert and the calculation of the lift distribution on the basis of Fourier series following Glauert have been completed so far that they are now in the position to calculate the optimum aerofoil section and plan form. It was therefore possible to fix each point on the surface of the Fafnir II by theoretically determined space co-ordinates. They reached the result that the performance of this machine that was calculated in complete agreement with theory was even better than the optimum required. It will therefore be understood that he had greater faith in theoretical calculations than in any measurements, which are always dependent on the special conditions of the test.

* H. Muttray. Die aerodynamische Zusammenfügung von Tragflügel und Rumpf. Luftfahrtforschung, Bd. 11, Nr. 5, 1934.

The correct design of the wing fuselage junction, on the other hand, logically leads to the tapered wing with relatively great taper as a great chord is required in the mid-wing portion to obtain as continuous a plan form as possible. As regards the flying qualities the wing with great taper has definite advantages as the rolling controllability is improved by the decrease of the induced yawing moment. In 1931 he pointed out " that first of all the designer must always realise that even a machine which is aerodynamically best will be incapable of good performances if it does not possess good flying qualities."

Tapered wings must, of course, be secured against premature stalling at the wing tips by corresponding twist. The twisted and tapered wing now leads to an increase of induced drag and the opinion has widely spread that this increase of induced drag diminishes the performances of the machine. But this conclusion merely takes into account the aerodynamic standpoint and does not consider that the structure weight of a tapered wing possessing a span that is aerodynamically equivalent to the elliptic wing is not greater than the weight of the elliptic wing. When using a tapered wing the bending stiffness is increased owing to greater height of the spar at the wing root. In this connection he wanted to draw the attention to a work of Prof. Prandtl in which he solves this problem in favour of the twisted wing with high taper.*

The calculation of the lift distribution and the distribution of the lift coefficients deduced therefrom shows in an obvious way how the twist has to be distributed over the wing. The distribution of the lift coefficient has to be corrected by the twist in such a way that the local maximum lift of the wing is obtained at the inner part of the wing. He reported on this problem in connection with " Method for the determination of the lift distribution along the span."† It is not necessary to make allowance for the stalling in the calculation as the distribution of the lift coefficient in the region of undisturbed flow informs them at which point of the span the stalling will start. In the dive case the tapered and twisted wing has negative lift at the wing ends and therefore experiences a negative bending moment at this outer part of the wing. If some experience in the design of wings has been gathered these negative bending moments will, however, not be greater than the positive moments in the case of centre of pressure forward.

This inversely equal bending load is, of course, only obtainable at certain points of the span, as for negative load the twist leads to a more ample load distribution at the outer portion of the wing. For correctly determining the dimensions of the structural elements that are to stand the bending and torsion of the wing, the calculation of the lift distribution has therefore to be carried through for different flight conditions. The method developed by them has proved very efficient in this respect as on the basis of this method it is possible to correlate the lift distribution of four elementary distributions, which are calculated separately and yield the required lift distribution when correlated corresponding to the special flight conditions.

If precisely defined requirements are given it is possible to calculate the wing plan form, the wing section and the aileron dimensions for different flight attitudes by means of a system of equations deduced from the calculation of the lift distribution. In this connection he wanted to mention the most valuable contribution of Prof. R. C. J. Howland and B. S. Shenstone.‡

In the design of a performance sailplane knowledge obtained from the aerofoil theory can be applied in a much higher degree than it is generally possible with powered aircraft. They must, however, really make use of this knowledge to reach maximum performances. In many cases this is not realised and a sort of recipes are used to construct the sailplanes.

It is, of course, simpler to join the wing bluntly to the fuselage wall and to point out on the basis of N.A.C.A. Rep. 540 that this combination is probably

* Prandtl, L. Uber Tragflügel kleinsten induzierten Widerstandes. Z.F.M., 1933.
† Luftfahrtforschung, Bd. 12, Nr. 3, 1935.
‡ The Inverse Method for Tapered and Twisted Wings. Philosophical Magazine, July, 1936.

even better if no fillets are used. It must, however, be said that a real " growth " is not contained in these tests and that the fillets inserted do not possess the correct sections. With these special aerodynamic problems the real solution cannot be found without theoretical considerations. This is, however, only recognised when such a " growth " is calculated and one realises how sensibly the lift distribution at this point is influenced by incorrectly designed sections. At any rate an unfavourable influence is exerted if the wing is joined to the vertical fuselage wall. In this case a considerable pressure difference is caused on the surface and a cross flow is formed running from the fuselage wall to the depression region on the wing. Muttray has drawn attention to this phenomenon in his tests on the influence of the fuselage on low wing combinations.* These difficulties can only be suppressed if the vertical wall is completely avoided on the upper surface of the wing. If for reasons of cheapness the adoption of the growth is not wanted it is advisable to design either a parasol or a connected high wing monoplane. As regards the considerations of cheapness he was of the opinion that this standpoint ought not to be decisive in the design of high performance sailplanes. If the construction of a large number is simplified by the use of formers or jigs even a good growth can be obtained without incurring high costs, although it may be difficult to construct with the first machine. He may perhaps draw a comparison with the construction of powered aircraft where the aerodynamic improvements have always to be carried through in spite of the difficulties of construction that were met at the beginning.

That, on the other hand, the smooth merging of wing and fuselage is seldom adopted in the design of motored aircraft is connected with the fact that the slipstream of the tractor airscrew causes unsymmetrical flow conditions on the fuselage and partly destroys the effect of the growth or sensibly influences the longitudinal stability.

He would now add a word on the question of tailless sailplanes. From the aerodynamic point of view the high performance sailplane with good growth is already approaching the tailless aeroplane and by adopting the tailless type there is not much to be gained. As the tailless sailplane also requires a large span and a good aspect ratio, the bending stiffness of the wing is not sufficient to provide a satisfactory elevator control. The elevators must therefore be located in the mid-wing portion where satisfactory control can only be obtained with slight sweepback. Of course there must exist other possibilities for obtaining a satisfactory elevator control in spite of low wing stiffness, but he must issue a warning to the effect that the question of the tailless sailplane should not be considered too optimistically. As a powered aeroplane the all-wing machine possesses certain definite advantages. With the design of sailplanes these advantages are, however, less essential. He believed that an intermediate type with arrangement of the elevator near the trailing edge will be the best solution.

The success that has been granted to the German soaring movement has in foreign countries often been ascribed to the fact that from 1925 they were in the position to build up a research institute with the help of public means and therefore to give the soaring movement a firm basis. Of course the soaring movement in Germany has been furthered by this fact. They must not forget, however, that from 1920 to 1925 the soaring movement has been carried on by men who put themselves at its disposal out of pure enthusiasm for the idea of powerless flight. During this time those men emerged who were able to carry on the soaring movement on a broader basis and to pass on the willingness to sacrifice for the sake of an ideal to the new adherents of the soaring movement. If therefore a comparison is drawn with the German soaring organisation from outside, the corresponding periods of the German soaring movement in the past must also be taken into account.

* H. Muttray. Versuche über die Ausbildung der Flügelwurzel an Tiefdeckern. Ergebnisse der Aerodynamischen Versuchsanstalt Göttingen. IV, p. 89, Fig. 132.

Symbols.

W/S = wing loading (lbs./ft.^{2}).
v_{sm} = mean sinking speed (ft./sec.).
A = aspect ratio.
ρ = air density (lbs. sec.^{2}/ft.^{4}).
$(1+\delta)$ = relation of the induced drag of a given wing to the minimum induced drag (elliptic wing).
v_m = mean speed of flight (ft./sec.).
Δv = velocity range (ft./sec.).
c_{Dpr} – coefficient of profile drag.
c_{Dpar} = coefficient of parasite drag.
c_r = coefficient of resultant air force.

Reply to Discussion.

Professor G. T. R. Hill.—The difficulty of measuring a gliding angle such as 1 in 26 directly is got over by measuring the forward speed and the rate of descent separately, and thus the gliding angle can be deduced. It is necessary to choose an occasion when the atmosphere is smooth and stable for making such measurements.

The torsional stiffness of the wing is necessary to postpone the onset both of aileron reversal and of flutter. German figures indicate that if the wing skin, which resists torsion, is laid with its ply diagonal to the shear stress, the torsional stiffness is increased four or six times.

The possibility of putting on the ply like this depends on workshop technique combined with suitable design. The ply skin on the wing tip of Hjordis was laid on diagonally, but it had a badly buckled surface and it was removed.

The bending stiffness of cantilever wings has decreased in some recent sailplanes owing to the use of thinner wing sections. Apart from its effect on the flutter speed, the flexibility of the wing has some effect on the mind of the pilot! Having been brought up on biplanes, I found at first that I disliked the sight of wings bending in flight; but I have now got used to it and rather like it.

Mr. W. O. Manning.—There is a lack of measured data of performance of sailplanes in this country and they are much needed. I look on a sailplane as a sort of aircraft model, on which experiments of this nature may be performed directly.

The construction of models of sailplanes for use in wind tunnels would have to be done with extreme accuracy if such experiments were to be successful, and the measurements of the characteristics of these models in wind tunnels might have errors caused by the turbulence of the tunnel.

I think the optimum area of a wing of given span is somewhat lower than Mr. Manning suggests. The performance of the Austria I seems to support this opinion. The need to combine a high forward speed with a low sinking speed affects the area of the wing.

The (spanwise) position of the initial stall in a tapered wing can be controlled by twisting it. Allowance must be made for the decrease of Reynolds number from the root to the tip and for the effect of sweeping the wing forwards or backwards. If some estimate has been made of the magnitude of these effects, and if the decrease from root to tip of the ratio (lift coefficient) : (maximum lift coefficient of section) has been chosen, the necessary twist can be calculated.

Mr. B. S. Shenstone.—An experiment which was suggested by Mr. Relf and Professor Melvill Jones bears on the problem of the skin drag of sailplanes. It indicated that the flow over a great part of the chord of a sailplane wing is laminar.

A plain copper tube of about an eighth of an inch external diameter was fitted in the wing so that one open end was exactly flush with the surface. The other open end was connected by a doctor's stethoscope to my ear.

On a wing of 42 inches (1,070 mm.) chord, whose section was Göttingen 652, no sound could be heard in a tube which was fitted at 10 inches (254 mm.) from the leading edge. Another tube was fitted in the top surface of the same section at 28 inches (710 mm.) from the leading edge; this tube was silent below 35 m.p.h. and made a sound which may be represented by " shrosh " above this speed. I assume that the flow changed from turbulent to laminar at this speed.

The surface of the wing was of ply varnished and polished.

The wing sections of the King Kite were chosen so that the lift coefficient of the section increases as the wing tip is approached. The lift coefficient that is required, owing to the shape of the lift distribution, decreases as the tip is approached so that the wing tip should stall after the rest of the wing.

We (Mr. P. Shaw, who was employed by Mr. Slingsby on the design of the King Kite, and myself) hesitated to use a symmetrical section at the tip as a larger twist would be needed. This gives an alarming kind of load distribution in inverted flight.

As a first step to investigating the suggestion that the speed of aileron reversal may be postponed by suitable design of the aileron, it is interesting to see in R. and M. 1095 that the pitching moment of a wing section with flap deflected decreases as the ratio (flap chord) : (total chord) increases to unity from about 0.25. When there is no aileron flap and control is got by varying the incidence of the part of the wing at the tip (as in the Ku. 7), the problem of aileron reversal is presumably eliminated. But so long as there is a flap, there is some pitching moment when it is deflected so that there will be an aileron reversal at some speed.

I hope that the technical committee of the British Gliding Association will consider and lay down criteria for lateral stability near the stall as an airworthiness requirement for sailplanes.

Mr. P. A. Wills.—So many pilots in the past have ventured into clouds with sailplanes which were not suitable for cloud flying, or without equipment for it, that I do not think that the designer can assume that the pilot will refrain from entering a cloud if the opportunity occurs.

On the other hand, if a pilot enters a cloud and loses control in it so that he emerges in an inverted diving attitude, it is not possible to suggest a manœuvre by which he can recover with certainty. If the pilot were travelling nearly horizontally, his best course would probably be to do a half roll by means of the ailerons, and if he were diving nearly vertically his best course would be to pull out by the elevators. The first statement must be qualified by saying that if the design of the wing included a large twist, the pilot should have found out what inverted conditions the wing is built for. The second by saying that the pilot must judge how firm the pull out is by the acceleration that he is experiencing, and that it may be necessary to " pull " out with a forward pressure on the stick to prevent the acceleration and thus the loads from becoming excessive.

A normal pilot with blind flying training and experience and in a suitable sailplane should avoid these situations. To do this, he must have a method of retreating from a cloud if he finds that conditions are not suitable for safe flying.

Mr. L. E. Baynes.—The body of a sailplane to conventional plan form may be designed as part of the wing. If so, the problem arises of maintaining a normal distribution of lift over the span of a wing which varies greatly in chord. This can be done by varying the incidence as suggested, but the lift distribution will then vary with the lift coefficient, and will be of the desired shape at one speed only.

If the fuselage is considered to be acting merely as a stop gap between the roots of the wings (the flow being streamline everywhere), the distortion of the distribution of lift owing to the fuselage taking the place of the middle of the wing will theoretically be slight in the case of a sailplane of high aspect ratio

and this distortion will be independent of incidence. Thus the fuselage which is a streamline " stop gap " may be a satisfactory compromise.

Mr. A. G. Pugsley.—The wing stiffness tests and flutter calculations for the King Kite show that the problems of flutter and stiffness have now become pressing.

It seems that the problem of aileron reversal must first be solved.

The ailerons should be designed so that the stiffness necessary to prevent reversal at the speeds required is as low as possible. When the ailerons have been designed for this result, the torsion resisting structure can be designed to provide the necessary stiffness. This structure will usually be a stiffened ply skin either over the nose of the wing section in front of the main spar, or continued back to the rear spar.

Then the problem of flutter must be considered.

The precautions against flutter on aeroplanes include the mass balancing, or the irreversible actuation, of the aileron. These precautions are not usually taken in sailplanes, but flutter does not occur even at comparatively high speeds such as 175 m.p.h.

The wing structure of a sailplane usually consists of a main spar in a forward position, and the plywood covering in front of the main spar. In this the King Kite is an exception, as Mr. Pugsley has pointed out. Thus the balance of the wing is well forward.

I have heard in Germany the opinion that engine vibrations help to excite aileron flutter, and that a mass balanced aileron is not so necessary in engineless aircraft. This effect of engine vibrations is considered in R. and M. 1155 and is not thought important. In Germany it is considered that it is important to place the masses of the wing as far forward as possible to avoid flutter, which is in accordance with Mr. Pugsley's view.

I suggest tentatively two possible causes of the absence of flutter: First, that the aileron control circuit is usually relatively stiff, being made of 10 cwt. cable, and second, that the elastic hysteresis of the structure gives sufficient damping.

The problem seems to be unexplained, and is one of importance.

Lord Sempill.—The information provided by Lord Sempill is a useful contribution to the paper, and I am glad there is an opportunity to place it on record.

Mr. A. R. Weyl (communicated).—I hope that the increasing number of soaring pilots may lead to an increase in the demand for sailplanes, and that this will enable manufacturers, with the help of the import duty, to compete with the prices of imported sailplanes. It is clear from Mr. Weyl's comments on production costs that when this becomes possible, we may expect an efficient sailplane from him.

I agree with Mr. Weyl that a more cambered section may be preferable. I had thought of calculating a section with greater camber than the N.A.C.A. 230 series, but with the same type of centre line curvature, but I was not able to consider this fully or to test any section of this type in a wind tunnel. I do not come to the same conclusion about drag, for I suppost that if the flow is laminar over a great part of the section, the drag is less.

In the King Kite, plain flaps are used, and she will come out of a spin with elevator alone whether the flaps are up or down.

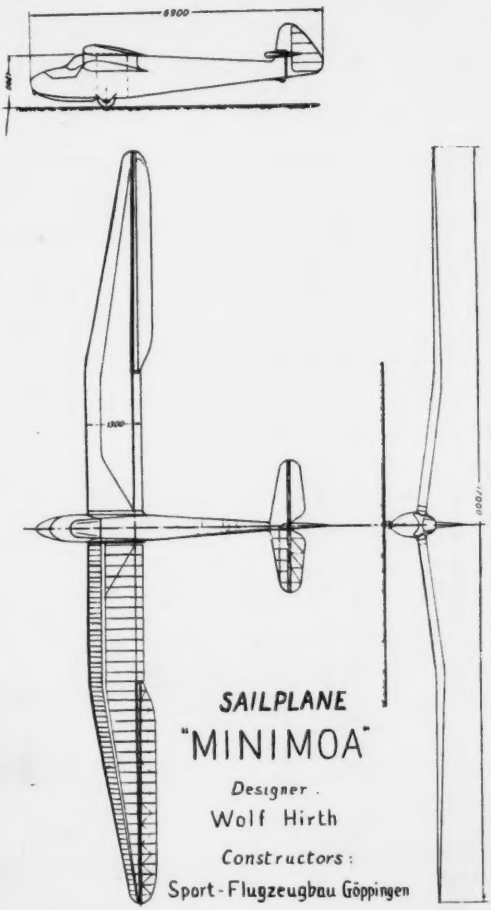
The centre of gravity is not as far forward as I proposed, and Mr. Weyl will agree that this is a fault difficult to correct at this stage. From a test there is some indication that the entry into a spin is smoother when the centre of gravity is more forward.

Mr. S. Scott Hall (communicated).—I hope that the Universities and Aeronautical Technical Colleges will play a part in the improvement of sailplane design. The undergraduate or student does not normally have time to acquire the knowledge for designing the sailplane, and to build it during his course. So that the production of a sailplane depends on some members of the permanent

staff being interested enough to act as the connecting link between successive generations of undergraduates.

I had meant to convey that I agree with Mr. Scott Hall that a streamline shape should if possible have a simply shaped cross section.

I regret that I have no information about soaring in Russia or in America. In America, I believe that a Minimoa imported from Germany was the winner in the last annual competitions.



It would, presumably, be possible to soar on a cold front at night, and the distance record may be increased by this means. The difficulty of providing night flying equipment for making such a flight lies in the need for adequate illumination of a landing ground to be maintained while the sailplane of low sinking speed descends.

Another possible method for improving the distance record is for the pilot to make a goal flight to a good soaring slope during one day, to spend the night slope soaring, having arranged beforehand for the necessary lights to be shown, and to continue the distance flight in the morning.

Herr Alexander Lippisch (*communicated*).—A contribution with the authority of Herr Lippisch is welcome, and there is little that I can add to his fundamental generalisation about turbulence and to the other points that he makes.

The tailless design seems to have certain advantages in sailplanes of moderate wing loading and moderate size. If I am able to develop such a design, I will pay attention to Herr Lippisch's warning. I am very glad that Herr Lippisch has contributed to the discussion.

SOME SAILPLANE DESIGN DATA AND INFORMATION FROM GERMAN SOURCES.

By B. S. Shenstone, *Associate Fellow.*

Squadron Leader Buxton has pointed out the lack of basic design data for sailplanes available in English. To alleviate this condition to a certain extent, the following data are presented. All the data are from German sources and

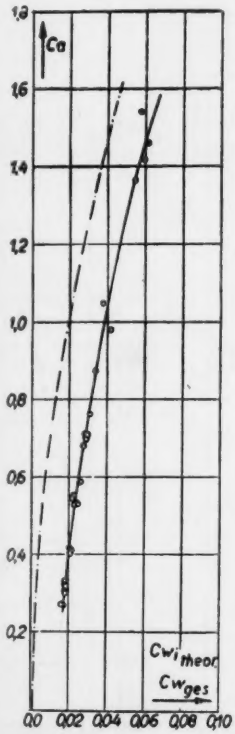


FIG. 12.*
Polar, Fafnir II.

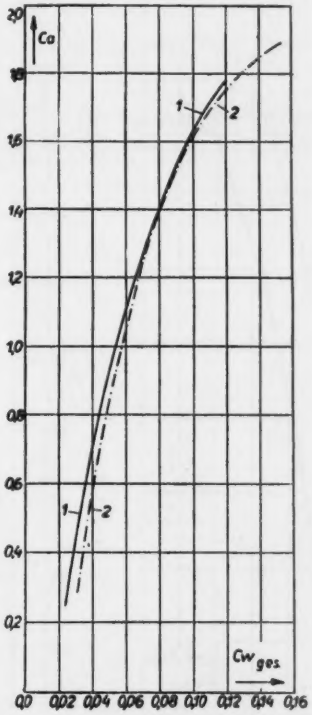


FIG. 13.
Polar, Sevadler.
1. *No floats.* 2. *With floats.*

the Society is indebted to Alexander Lippisch, A.F.R.Ae.S., and to the Deutsche Forschungsanstalt fuer Segelflug for much of the information. It is sub-divided as follows:—

* In the polar curves $C_a = C_L$ (lift coefficient), $C_{wi} = C_{Di}$ (induced drag coefficient), $C_{w_{ges}} = C_D$ (overall drag coefficient).

1. Drags of Sailplanes.
2. Structure Weights of Sailplanes.
3. Air Brakes for use when Diving.
4. Structural Notes—(i) The aerobatic sailplane " Habicht."
   (ii) Metal construction.
5. Strength Requirements for Sailplanes (German).

1. Drags of Sailplanes.*

The data given in this section have been obtained by full-scale measurements on actual sailplanes in flight. The most interesting data is given in Table I in the form of measured performances. The polars of the sailplanes are given in Figs. 12-16, and general arrangement sketches are given in Figs. 17-22 so that the effects of differences may be studied and any other details of performance estimated.

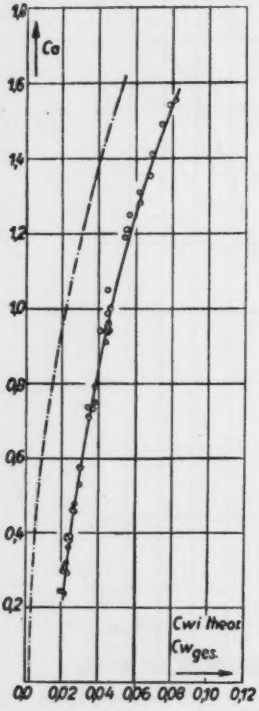


FIG. 14.
Polar, Sperber.

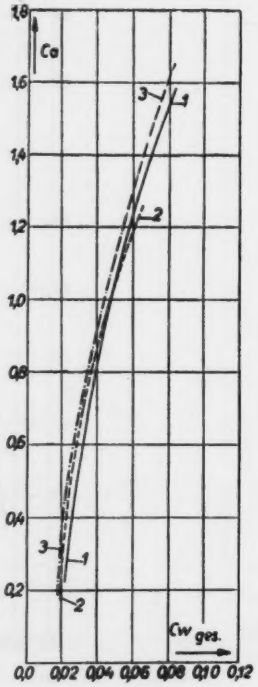


FIG. 15.
Polars: Sperber II. 1.
Sperber Sr., 2.
Sperber Jr., 3.

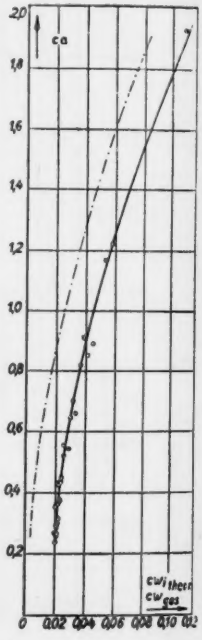


FIG. 16.
Polar, Kranich.

METHOD OF MEASUREMENT OF PERFORMANCE.

The sailplanes were towed by aeroplane to a suitable altitude which varied between 6,500ft. and 1,300ft., and, after being set free, made glides at constant

* " Flugleistungsmessungen an verschiedenen Segelflugzeugen " von W. Spilger. Jahrbuch 1937 der Deutschen Luftfahrtforschung, p. I-293.

indicated air speeds, during which the air pressure, air speed, temperature and relative humidity were measured simultaneously.

The weather was chosen so that the vertical air currents would be as small as possible, suitable conditions being those with stable layers of air both on the

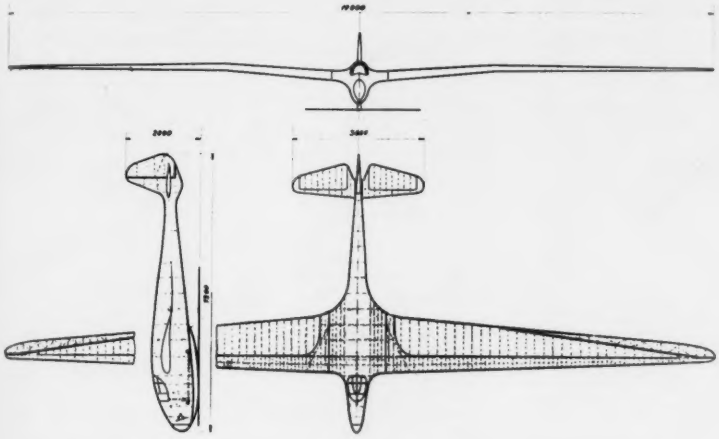


FIG. 17.
Sao Paolo (Fafnir II).

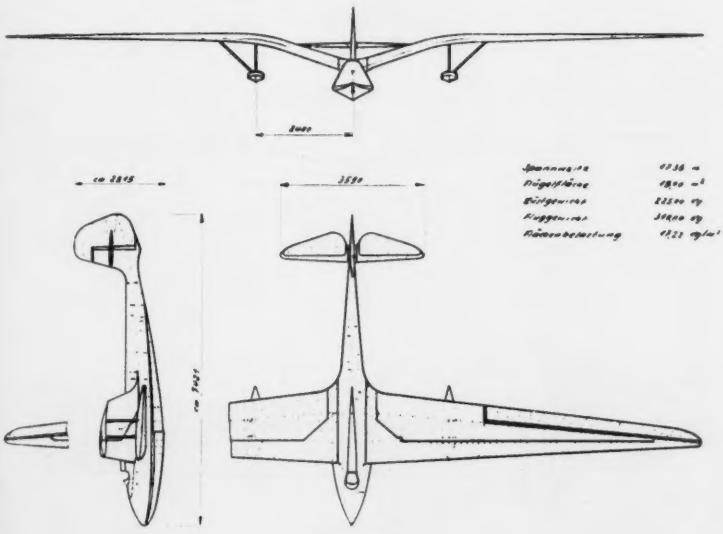


FIG. 18.
Seeadler.

ground and at altitude, and with a completely overcast sky. The flights were made between dawn and 8 a.m. The times of glides depended on the speeds and varied between one and five minutes in duration, so that the probable error in the readings would be the same for all speeds (about ± 2 per cent.).

Gliding speeds varied between 30 and 80 m.p.h. I.A.S. Air pressure and air speed were registered on a quadruple Askania instrument. With this instrument 1 to 4 quantities may be synchronously registered on a strip of light-sensitive paper about 5 inches wide which can be moved at any speed between 0.05 and

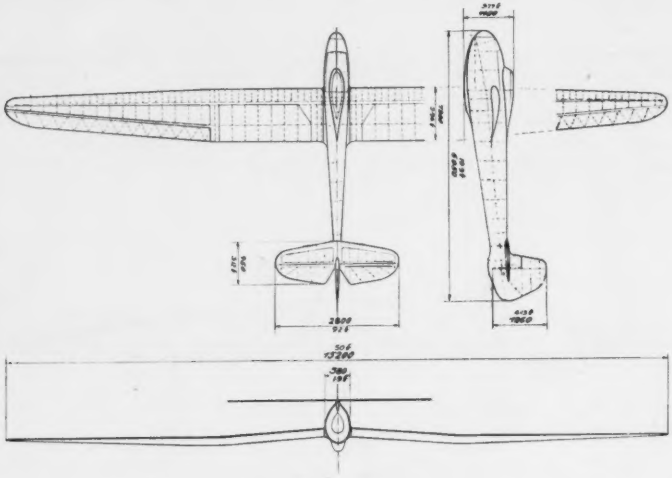


FIG. 19.
Sperber.

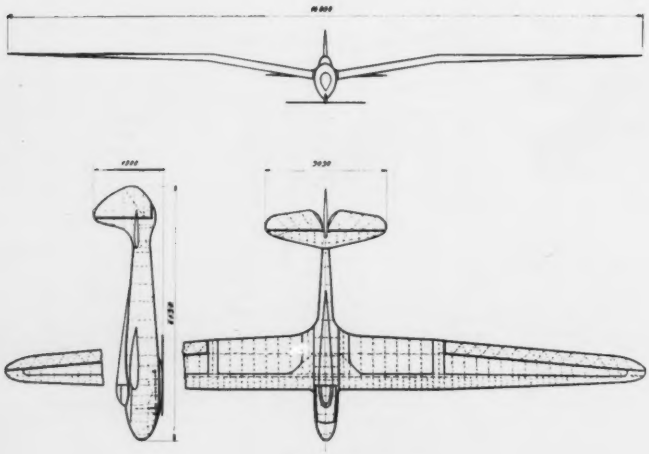


FIG. 20.
Sperber Senior.

10 mm. per sec. A time scale is also marked on the strip. The air density was measured by registering air pressure, temperature and relative humidity on a meteorograph carried by the towing aeroplane.

In nearly all cases the accelerations in the vertical plane were measured. The amount of acceleration served as a criterion of the degree of large scale air movements and in conjunction with small scale air movements is to be used as a

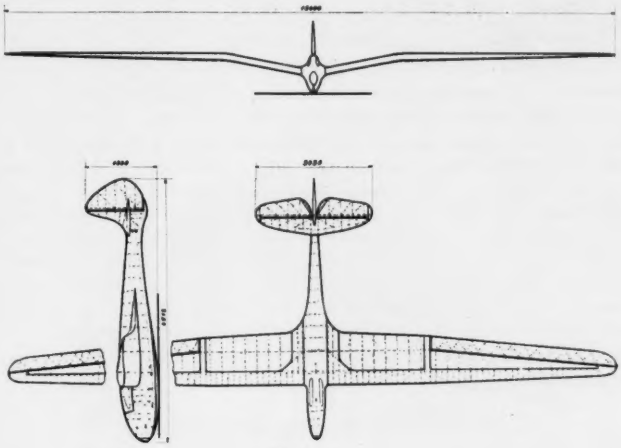


FIG. 21.
Sperber Junior.

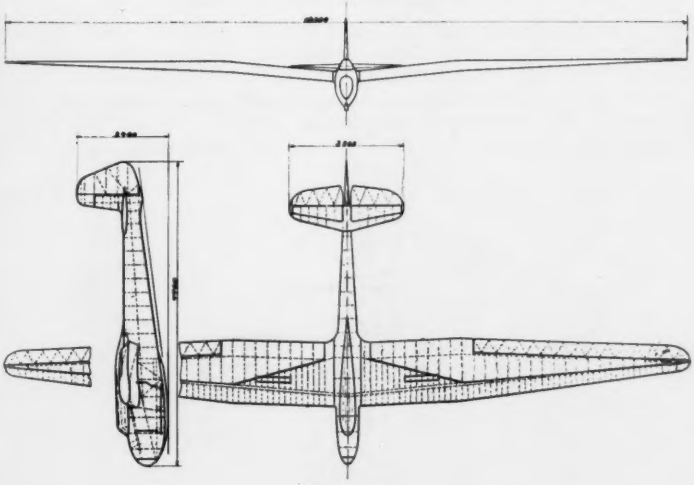


FIG. 22.
Kranich.

basis for estimating the effect of such movements on performance by statistical methods.

To determine the polar of each type, about 10 flights were necessary and in each flight three or four runs at different speeds were made.

NOTES ON MEASUREMENT OF SINKING SPEED AND AIR SPEED.

The true sinking speed was determined as:—

$$v_s \text{ (m./sec.)} = (\Delta b/\Delta t)\,(1/gp\sqrt{\sigma})13.596 = (\Delta b/\Delta t)\,(11.1/\sqrt{\sigma})$$

where Δb = air pressure difference (mm. of mercury) corresponding to the altitude difference being considered.

Δt = corresponding time interval in seconds.

σ = relative density based on mean altitude over which Δb was measured.

The accuracy of measurement of the sinking speed, after careful consideration and experiment, has been determined as ± 2.06 per cent.

The airspeed for all types except the Wanderkranich was measured by the Kiel arrangement of Prandtl tubes, which consists of two tubes, one below and one above the wing, attached to a strut passing through the wing. The static pressure was determined by taking a certain definite proportion of the pressure from each tube. In the case of the Wanderkranich, the usual Prandtl tube was used and it was calibrated by the use of a suspended pitot. The indicated air speed was measured by means of a sensitive pressure difference element and registered. An examination of the possible sources of error showed that for most speeds the accuracy was ± 4 per cent. and for the lower speeds ± 5 per cent.

From the sinking and the flight speeds, the gliding angle and hence the polar are easily determined.

2. Structure Weights of Sailplanes.

The weight taken for pilot and parachute is 85 kg. (187lb.). In comparing these weights with those in Part I, it must be remembered that about 20 kg. (44lb.) of instruments were carried for the performance testing.

3. Air Brakes for use when Diving.*

In order to reduce the diving speed and thus the pull-out loads, the air brake scheme illustrated in Fig. 23 has been developed. The top brake opens forward and the lower brake aft. The brakes consist of flat metal plates (with stiffeners) totalling (four plates, two each wing) about $4\frac{1}{2}$ per cent. of the wing plan area, the gap between the brake and wing being included in the brake area. The chord of each flap is about 12.5 per cent. of the local wing chord, the aspect

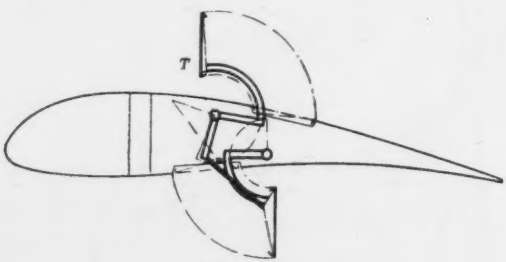


FIG. 23.
Air brakes.

ratio of each flap being of the order of 4. The spanwise position used is with the outer end of the brake slightly inboard of the inner end of the aileron. In normal flight they are retracted flush with the wing surface and so do not affect normal flying. The arrangement illustrated is so adjusted that the control loads necessary to open the brakes are initially heavy, to guard against too rapid

* Luftbremsen fuer Segelflugzeuge " von Hans Jacobs. " Luftwissen," Bd. 4 (1937), Nr. 7.

diagonal coming from the main spar, the space between it and the diagonal being boxed in. Thus the shear is gradually taken out of the leading edge skin and distributed over the larger box. In the case of the " Habicht," as much of the torque as possible was kept in the leading edge right up to the root and then transferred backwards by a strong root rib. The usual diagonal was present, but did less work than usual, and in this manner considerable weight was saved. But a difficulty arose where the heavy rib crossed the spar, the result being a sudden increase in section which was immediately reduced again. By rounding the corners by filler blocks, the tendency toward failure due to concentration of stress was avoided. The wing root arrangement is shown in Fig. 27.

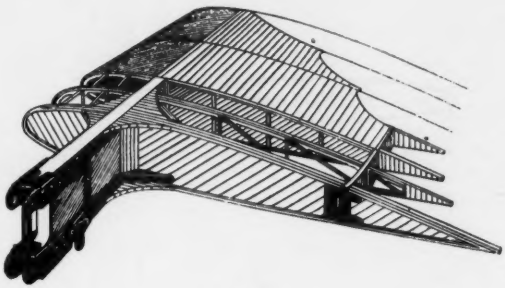


FIG. 27.
Wing at root.

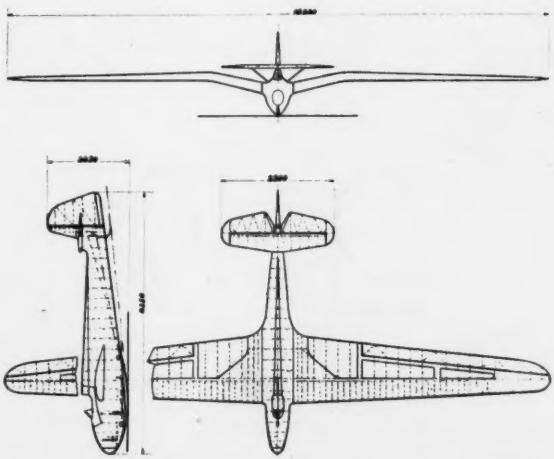


FIG. 28.
Habicht.

FUSELAGE.

The fuselage (see Fig. 26) was designed with two groups of four stringers arranged so that the ply would help in the load-carrying considerably. The width of the ply fields between stringers was about 60 times the ply thickness, so that the effective width was much greater than usual, and weight was thereby saved. This arrangement also prevented local buckling under shear. Between the spar

opening and overloading the sailplane. When open they remain open, however, due to the air forces. Thus they require considerable control load to start the retraction, guarding against any sudden movements. Pilot's control is by a hand lever at his left, the operation through the wing being by torsion tube (*T* in Fig. 23). The gap between the wing and the brake is of importance as it noticeably improves the longitudinal control and steadies the flow, compared to a brake which touches the wing.

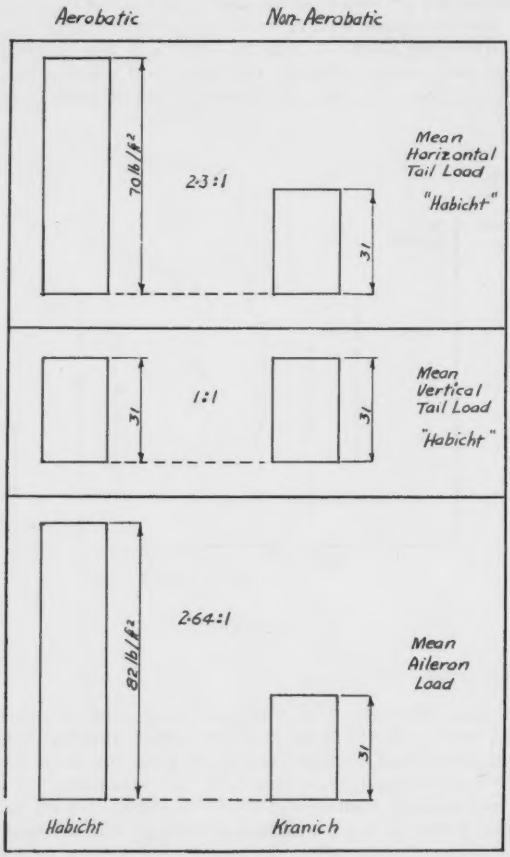
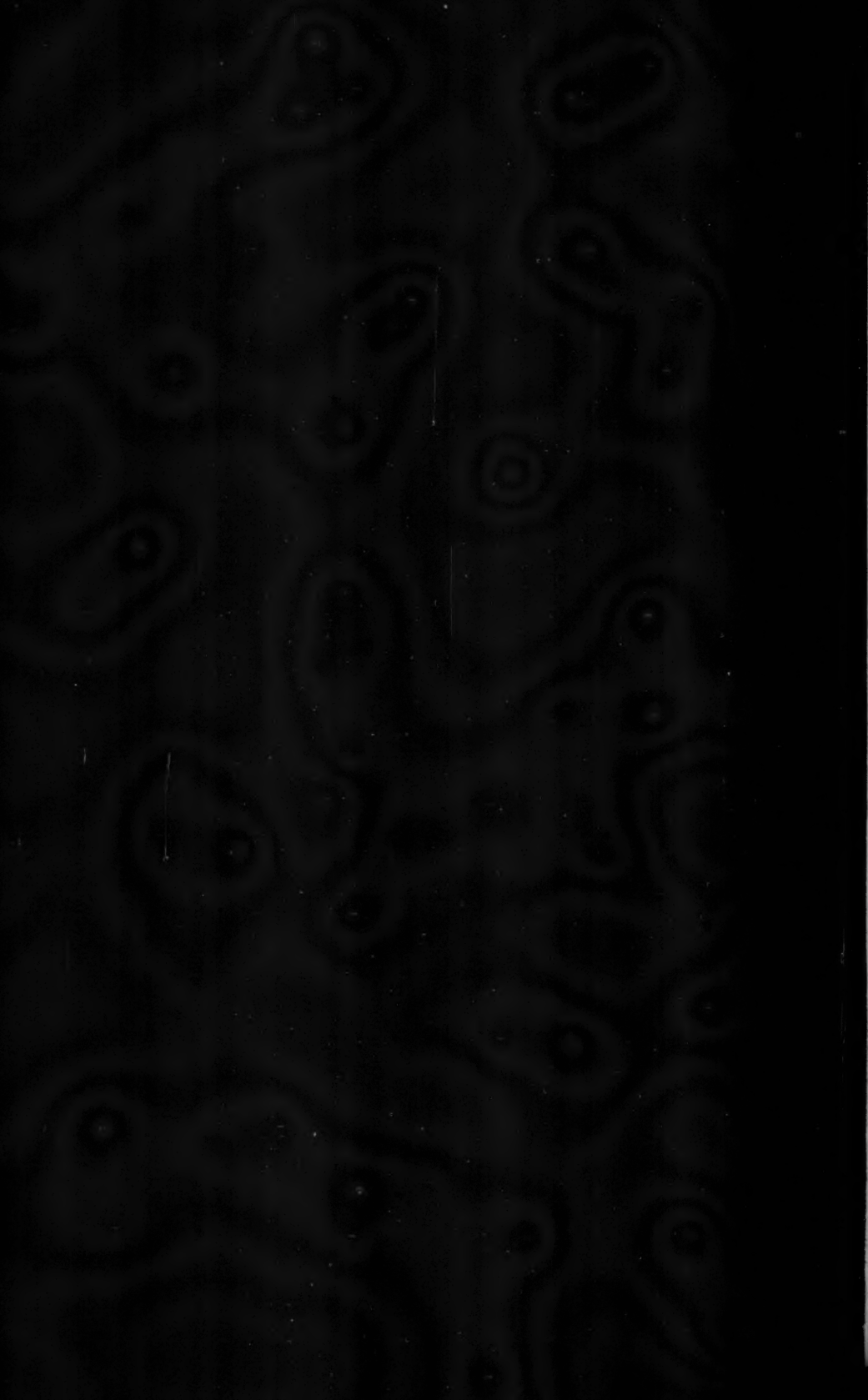


FIG. 24.

Control surface loadings.

Full-scale tests showed that on the Rhoensperber the brakes reduced the diving speed from 415 k.p.h. (258 m.p.h.) to 190 k.p.h. (118 m.p.h.). Working back from this result, a drag coefficient based on the brake area (including gap) of $C_D = 2.007$ results. This can be used in estimating the size of brake required in any design.

Such brakes have been tested under all conditions and have been found satisfactory and safe.



4. Structural Notes.

(i) The Aerobatic Sailplane "Habicht."

This type was developed specially for aerobatics after normal types (*CPF* factors of 8) had experienced structural failure, particularly in inverted loops. The design is particularly interesting in several respects. Everything possible was done to increase factors (*CPF* = 12) without adding more weight than absolutely necessary, since in a sailplane the structural weight can affect its flying characteristics and performance to a greater extent than that of a powered aeroplane, since the structure weight is a far greater percentage of the gross weight. In the following notes it will be seen how the strength requirements affected the design and construction of the type, and particularly how necessary it is to make strength tests during the development of such a type.

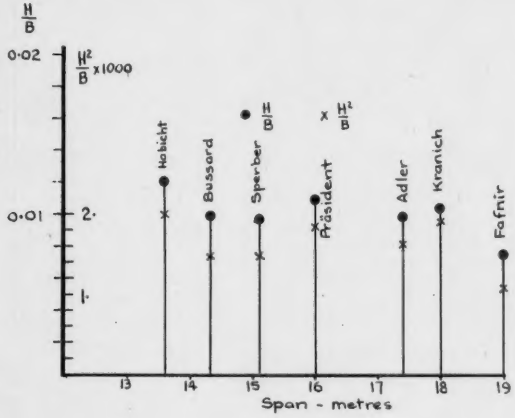


Fig. 25.

Stressing Assumptions.

Instead of the usual ultimate *CPF* factor of 8 as used in non-aerobatic types, a factor of 12 was used. In the nose dive the actual terminal velocity was taken instead of a speed about half as great which is used for normal types. For the normal cases, see the Strength Requirements for Sailplanes. Fig. 24 compares the factored control surface loadings of the "Habicht" with normal and aerobatic factors. The great increase in elevator and aileron loading is to be noted.

Effect of Increased Loading on the Design in General.

(1) Wing.

(*a*) The ratio mean spar depth/span was kept as large as possible, as a large value of the spar depth increases stiffness and decreases liability to flutter. Fig. 25 shows the values of this ratio (H/B) and also of H^2/B for a number of successful types, so that from a statistical point of view, it is seen that a mean spar depth equal to 1/100 of the span is satisfactory,

(*b*) Diagonal ply was used on the wing leading edge, which gives 3.2 times the stiffness of straight-laid ply.

(*c*) A large wing taper was used. This is an obvious weight-saver.

(*d*) By careful choice of twist distribution it was possible to reduce the stresses in the nose-dive case considerably. At the same time it was possible to keep the washout suitable for control at large incidences.

(2) FUSELAGE.

As is seen in Fig. 26 the fuselage was made much fuller in section in the aft portion than is usual, as shown by comparison with the "Sperber." The fuller shape enabled a much stiffer fuselage to be made with a minimum of weight.

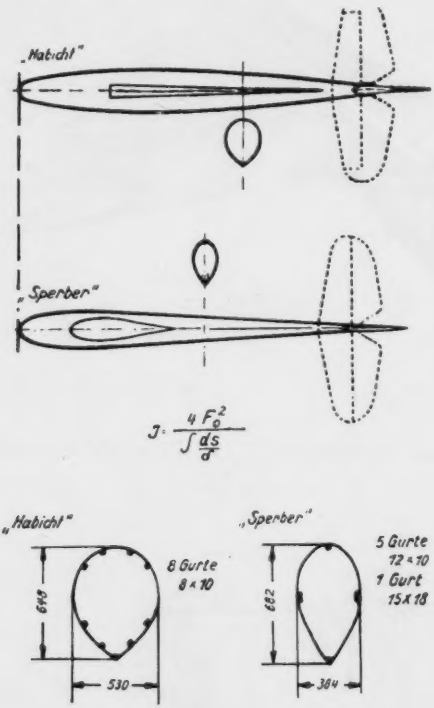


FIG. 26.

Comparison of fuselage shapes.

EFFECT OF INCREASED LOADING ON THE STRUCTURE.

The loadings resulting from the terminal velocity dive and a continuous turn in the dive give rise to heavy wing torsion and tail loads and to large shears and bending in the fuselage, the shear being particularly severe between the front and rear spar attachments.

WING.

The plywood leading edge on the single spar structure has a maximum thickness of 3 mm. (about $\frac{1}{8}$in.). Of particular interest is the design of the wing root. As is usual, the torque is taken off at a rear attachment and the main spar, but not at the leading edge. The rear attachment is merely the end of a

Type.	Fafnir II.		Seeadler.*		Sperl
Span	19 m.	62.3 ft.	17.36 m.	57 ft.	15.2 m.
Wing Area	17.7 m.²	189 ft.²	18.8 m.²	202 ft.²	15.3 m.²
All-up wt. on Test Wing	382 kg.	840 lb.	374 kg.	822 lb.	270 kg.†
Wing Loading	21.6 kg./m.²	4.45 lb./ft.²	19.9 kg./m.²	4.07 lb./ft.²	17.6 kg./m.²
Max. L/D	26		19		21
Speed at Max. L/D	56.5 k.p.h.	41.2 m.p.h.	64 k.p.h.	39.8 m.p.h.	63 k.p.h.
Minimum Sinking Speed	0.63 m./s.	2.06 f.p.s.	0.84 m./s.	2.76 f.p.s.	0.73 m./s.
Root Wing Section	Special		G.652		G.5
Tip Wing Section	Special		G.409		G.4
Wing Aspect Ratio	20.4		16		15

* Without tip float

Type.	Fafnir II.		Seeadler.		Sperber
C.P.F. factor	8		8		8
Wing wt.	2×67.7 kg.	2×149 lb.			2×56 kg.
Fuselage wt. Vertical Tail wt.	136.6 kg.	301 lb.			60.5 kg.
Tailplane weight Elevator Weight	6.6 kg.	14.5 lb.			7.6 kg.
Total Structure	280 kg.	614 lb.	240 kg.	528 lb.	180 kg.

TABLE I.

Sperber.		Sperber Senior		Sperber Junior.		Kranich.	
5.2 m.	50 ft.	16 m.	52.5 ft.	15.6 m.	51.2 ft.	18 m.	59 ft.
5.3 m.²	165 ft.²	16.2 m.²	174 ft.²	15.9 m.²	171 ft.²	22.7 m.²	244 ft.²
70 kg.†	595 lb.†	285 kg.†	627 lb.†	275 kg.†	605 lb.†	465 kg.	1020 lb.
7.6 kg./m.²	3.6 lb./ft.² 21.6	17.6 kg./m.²	3.6 lb./ft.² 22.7	17.3 kg./m.²	3.54 lb./ft.² 24.3	20.5 kg./m.²	4.2 lb./ft.² 22.5
3 k.p.h.	39.1 m.p.h.	67 k.p.h.	41.5 m.p.h.	68 k.p.h.	42.2 m.p.h.	38.5 k.p.h.	42.5 m.p.h.
73 m./s.	2.4 f.p.s.	0.74 m./s.	2.43 f.p.s.	0.65 m./s.	2.13 f.p.s.	0.75 m./s.	2.46 f.p.s.
G.535		G.757		G.535		G.535	
G.409		G.676		G.409		G.409	
15.1		15.8		15.3		14.3	

ut tip floats. † Approximate weight.

TABLE II.

Sperber Senior.		Sperber Junior.		Kranich.		Habicht (Aerobatic)	
8		8		8		12	
×56 kg.	2×123 lb.	2×50.5 kg.	2×111 lb.	2×80 kg.	2×176 lb.	2×69 kg.	2×152 lb.
				84 kg.	185 lb.	67 kg.	147 lb.
60.5 kg.	133 lb.			3 kg.	6.6 lb.	3 kg.	6.6 lb.
		68.2 kg.	150 lb.				
7.6 kg.	16.7 lb.			5.4 kg.	11.9 lb.	8.8 kg.	19.4 lb.
				4 kg.	8.8 lb.		
0 kg.	396 lb.	170 kg.	373 lb.	257 kg.	565 lb.	217 kg.	477 lb.

diagonal coming from the main spar, the space between it and the diagonal being boxed in. Thus the shear is gradually taken out of the leading edge skin and distributed over the larger box. In the case of the " Habicht," as much of the torque as possible was kept in the leading edge right up to the root and then transferred backwards by a strong root rib. The usual diagonal was present, but did less work than usual, and in this manner considerable weight was saved. But a difficulty arose where the heavy rib crossed the spar, the result being a sudden increase in section which was immediately reduced again. By rounding the corners by filler blocks, the tendency toward failure due to concentration of stress was avoided. The wing root arrangement is shown in Fig. 27.

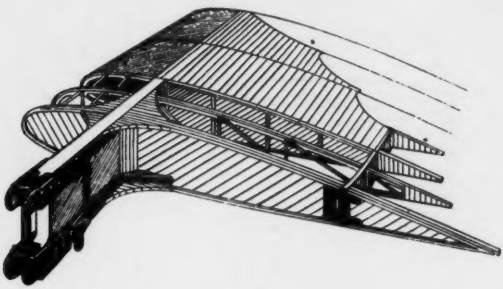


FIG. 27.
Wing at root.

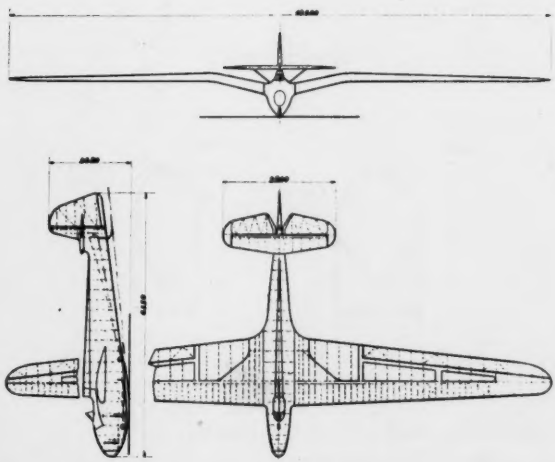


FIG. 28.
Habicht.

FUSELAGE.

The fuselage (see Fig. 26) was designed with two groups of four stringers arranged so that the ply would help in the load-carrying considerably. The width of the ply fields between stringers was about 60 times the ply thickness, so that the effective width was much greater than usual, and weight was thereby saved. This arrangement also prevented local buckling under shear. Between the spar

attachments a factored shear of 5,000lb. had to be taken. The fuselage panels in this region were cross-braced with diagonal stiffeners and the 1.5 mm. ply was laid on diagonally.

TESTING.

A fuselage and also an inner wing were tested to destruction and careful analysis made of the loads and deflections. Space forbids any details to be given here, but details are given in " Festigkeitsgrundlagen des DFS-Kunstsegelflugzeuges ' Habicht,' " published in the " Jahrbuch 1937 der Deutschen Luftfahrtforschung."

From the general arrangement of the " Habicht " shown in Fig. 28 several interesting features are seen. The raised tailplane and the rudder with wide chord near the bottom are particularly favourable to good spin recovery. The rib spacing in the nose of about 6in. and aft of the spar of about 12in. are the same as used for normal sailplanes. It is noted that there is a fixed tailplane of considerable size, which appears to be coming in for all types of sailplane. One curious feature is the use of unshielded elevator horn balances of a type seldom used in England.

Weights for the " Habicht " are given in the section on structure weights. Dimensions are as follows:—

Span	13.6 m.	44.6ft.
Wing area	15.82 m.^{2}	170ft.^{2}
All-up weight	302 kg.	665lb.
Wing loading	19.1 kg./m.^{2}	3.91lb./ft.^{2}
Wing aspect ratio	11.7	11.7

(ii) METAL CONSTRUCTION.*

For many years welded steel fuselages have been used for sailplanes, but usually for machines not having quite first class performance. The fundamental difficulty in such layouts is that they are not easy to repair in the field, since welding equipment and a skilled operator are necessary. The D.F.S. has studied this problem very carefully from the standpoint of producing methods of construction on which repairs can be made in the field easily. The use of riveted light alloys appeared most promising. Some special riveting tools originally sold as toys were developed into more useful forms and a system of construction evolved, using a limited number of standard shapes. Many test specimens were made and loaded, and a complete two-spar wing was manufactured. The difficulties involved in the manufacture of a D-nose spar are very great in light gauge metal and a first class finish or smoothness is not possible. At present the general opinion is that for control surfaces the use of light alloys is advantageous, but for larger and more complex items, the saving in weight is not worth the great difficulty involved in the design and manufacture. An example of the simpler forms of control surface of rectangular plan had a weight of about 0.28lb./ft.^{2} for an area of about 5ft.^{2}, weighed without fabric covering.

5. Strength Requirements for Sailplanes (German).

Translator's Note.—The following is a complete translation of the Strength Requirements for German Sailplanes in force in January, 1938. They have been developed from the requirements for aeroplanes by the Deutscher Luftfahrzeug-Ausschuss, Berlin-Adlershof. They are still in a state of development, the edition here being the third. The gaps in the numbering of paragraphs, cases, figures, etc., are in the original and do not indicate omissions. The arrangement of the requirements is as follows:—

* " Leichtmetallkonstruktion im Segelflugzeugbau " von L. Roth. Lilienthal-Gesellschaft fuer Luftfahrtforschung. Jahrbuch 1936.

Part I.—General Remarks on Safety and Strength.
Part II.—Loading Cases—
Loadings due to: Air Loads.
Ground Forces.
Handling Loads.
Part III.—Particulars Relative to the Carrying Out of Strength Calculations.

Part I.

General.

(*A*) Nature and Scope of the Regulations for Strength Requirements.

I. Nature of the Regulations.

1001. The following are minimum requirements derived, with simplified assumptions, from experience hitherto accumulated from flying practice and fixed in round figures.

Departures from the regulations may be permitted or required by the authorities if they are considered justified on the basis of definite knowledge or necessary for reasons of safety.

The requirements may be modified at any time to conform to newly acquired knowledge.

II. Scope of the Requirements.

1002. The requirements apply to every sailplane to be examined in all its parts including all installations or devices, any damage to which would be detrimental to the efficient working of the sailplane or the safety of its occupants, in such a manner that every load case to be assessed will be investigated with regard to its effect throughout the whole sailplane.

(*B*) Safety.

I. Safe Loading Conditions and Factors of Safety.

(*a*) Definitions.

1004. 1. The loading cases included in Part II of the following requirements, unless otherwise stated, are defined as " safe " states of stress, *i.e.*, such states of stress, the occurrence of which may be expected with a certain degree of probability during the working life of a sailplane, and such that states of still higher stresses are to be regarded as exceptional. The forces, velocities, absorptions of energy, etc., appropriate to the safe states of stress, *i.e.*, the *safe* forces, velocities, absorptions of energy, etc., determined according to the various requirements, are parameters for the strength calculations and as a rule do not denote any maximum values arising physically.

In addition to the safe states of stress, other states come into consideration which are to be regarded as exceptionally unfavourable, also states which, in spite of the low degree of stress as such, may in the course of time, as a result of their frequent recurrence, lead to fatigue failures.

2. Meaning of the Safety Factors.

1005. Factors of safety " j " are numbers by which the *safe* forces, velocities, absorptions of energy, etc., are in general to be multiplied when carrying out the strength calculations according to the rules given under *B*, I (*b*). The values obtained in this manner for the (external) forces, velocities, absorptions of energy, etc., represent those values with which definite danger limits would just be reached. Furthermore, the factors of safety are intended to make allowance for diminutions of the strength which are small and therefore not generally recognisable and difficult to define numerically, such as may occur owing to inaccuracies in production and calculation or also in operation. (In the

case of proportional increase of the stresses at the danger limits defined under items 1009 to 1015 by the given factors of safety, definite " permissible stresses " may be obtained which would be just reached with safe load.)

(*b*) General Rules for the Application of the Factors of Safety.

1006. In general the factors of safety are to be applied according to the following rules:—

1. With regard to stresses (yield point, ultimate stress, limit of stability).

(α) for " safe " loads.

1009, 1010. With $j=2$, *i.e.*, at twice the safe loading, the load-carrying ability of the structure may be exhausted so that the point of failure is reached in compression, buckling, shear or tension or any stability failure.

(β) for " frequently variable " loads.

1015. With $j=1.35$, *i.e.*, at 1.35 times the sum of the static load and the extra alternating load, those limits of stress may just be reached, beyond which, with the number of the load alternations expected during the whole life of the sailplane, a fatigue failure of the structure component would result.

2. With regard to the critical speed.

1020. With $j=1.3$, *i.e.*, at 1.3 times the maximum speed used in the calculations (see below) the critical speed may just be reached. The critical speed is the speed at which induced oscillations first occur, or at which the wing or control surfaces reach the limit of so-called structural stability (reversal speed). If no lower speed is laid down in the certificate of airworthiness, the maximum speed is to be at least that which at $\rho=0.12$ kg.^{2}/m.^{4} (0.00228 slug/ft.^{3}) results from the dynamic pressure given in case No. 100.

1021. If freedom from oscillation can be proved by flight tests at the maximum speed, the safety factor may be reduced to 1.0 if agreed by the authorities even although 1.3 times the maximum speed lies within the ability of the sailplane.

3. With regard to deformations.

1028. At $j=1.0$, *i.e.*, at 1.0 times the safe load, at no point may permanent deformations occur which exceed 5 per cent. of the total deformations produced under safe load. Permanent deformations up to 5 per cent. of the total deformation produced under safe load may be allowed with the approval of the authorities.

1029. With $j=1.0$, *i.e.*, at 1.0 times the safe load, if the control surface lever (at the surface) is held rigidly, at no part of the surface may the angle of twist be greater than 3.6°.

1030. With $j=1.0$, *i.e.*, at 1.0 times the safe load, in the case of non-mass-balanced auxiliary control surfaces connected to the control surface by a self-locking device or controlled by the latter through the medium of a rod, no cross-section of the auxiliary control surface may, owing to torsion of the auxiliary control surface or owing to the flexibility of its locking or coupling organs, undergo an angular displacement exceeding 3.6° relative to the control surface.

1031. With $j=1.0$ in cases 400, 402 and 420, *i.e.*, with 1.0 times the safe load in cases 400, 402 and 420 with the control levers (on the control surfaces) held fast, no movement of the points of application of the control force due to deformation of the control system may exceed 20 per cent. of the total possible positive or negative distance of displacement of the control concerned.

1032. With $j=1.0$, *i.e.*, 1.0 times the safe load in case 476, the point of application of the force may be displaced, as a result of deformations of the seat or the connections of the safety belt (in the case of a safety belt assumed as being non-elastic) by an amount not exceeding 5 cm. in the direction of the force.

With $j=2.0$ in case 476, *i.e.*, 2.0 times the safe load in case 476, the back of the seat must not bend to such a degree that the back of the seat or any part of the latter will continue to act only as an element of tension with the absorption of the force from the shoulder harness.

1034. With $j=2.0$ in case 475, *i.e.*, 2.0 times the safe load in case 475, the point of application of the force may, as a result of deformations of the seat or

the connections of the safety belt (in the case of a safety belt assumed to be non-elastic), be displaced an amount not exceeding 2 cm. in the direction of the force.

(*C*) Strength Calculations.

I. General Rules.

1060. The fulfilment of the safety requirements specified under items 1004 to 1055 must be verified by calculation or test according to the latest stage of knowledge. Hence, unless otherwise stated, it must be shown that, as a consequence of tolerances, the factors of safety are not reduced by more than 10 per cent. of their specified value. The fulfilment of item 1028 need, however, only be proved for such sailplanes and parts for which the experimental verification of the strength qualities is required in accordance with 1063.

1061. In the strength calculations the following must be dealt with:—

(*a*) All load cases referred to in the strength requirements, in so far as their consideration is not limited to definite stress groups or otherwise restricted.

(*b*) All states of stress essential to the strength of the sailplane which are not included individually in the strength requirements, the occurrence of which, however, is established, for example, when testing or flying the sailplane.

1063. Should there be any doubt as to the applicability of any method of calculation, experimental verification of the applicability of the method or experimental verification of the strength may be required.

Independently of this, experimental verification is, however, always required for:—

1. The foremost and rearmost position of the c.g. to be assumed for the determination of the forces on the tail unit.

2. That, in the case of wing or tail surface oscillations, no oscillations can occur in the control surfaces owing to coupling of the masses as a result of the displacement of the c.g. of the individual cross-sections of the control surfaces from the hinge line of the control surface, such as may promote the production of flutter phenomena (*cf.* 1078).

1075. In load tests, carried out for the verification of the strength qualities required under *B* I, the load which the system under test sustains up to the exhaustion of its supporting capacity, under the following conditions, is regarded as the experimentally proved supporting capacity:—

1. With continuously increasing load, after reaching the safe load, the increase per minute must not exceed 20 per cent. of the safe load.
2. With load increasing by stages, the structural part being supported or raised during the placing of the load, or when the placing of the loads of the individual stages (the part under test not being supported or raised) takes place more rapidly than with the continuously increasing load as under (*a*), the load stages shortly before exhaustion of the supporting capacity must not exceed 20 per cent. of the safe load. The system under test may again be supported or raised for the purpose of making a further increase of the load, only if it has carried the load placed upon it for 30 seconds without exhibiting signs of the exhaustion of its supporting capacity.

If the structural part in case (2) supports the load for a period of not less than 30 seconds after complete lowering of the supporting system, the load for this stage is counted as the experimentally proved supporting capacity, otherwise the preceding stage must be taken.

(*b*) Oscillation Tests.

1078. The proof, required in accordance with 1063 (2) that no coupling of the masses exists such as would tend to induce oscillations owing to displacement of the c.g. of the individual cross-sections of the control surface relative to its hinge

axis, is considered as being given, if the control surfaces, when the whole aeroplane suspended in a highly elastic mounting with the control system disconnected from the surfaces, reveal similar oscillation qualities in the shake tests as would be anticipated if complete mass-balance existed, *i.e.*, if each individual cross-section of the control surface coincided with the axis of rotation. These shake tests must extend at least to all frequencies n, whose reduced value $\{ n\pi c_m(n) \} / v$ (with $v = 1.3\ v_{max}$ in accordance with 1020 and $c_m(n)$ in accordance with 1540) is equal to or less than 0.9.

Couplings between control surface oscillation and wing or fixed tail surface oscillations due to the c.g. position being ahead of the hinge axis of the control surface may be permitted, if proof is provided that a greater safety against oscillations is thereby attained than with perfect mass-balance.

The present rules do not apply to further oscillation tests carried out in connection with the proof of the safety required in accordance with 1020.

III. Weights of Persons and Parachutes.

1080. The weight of one person, including parachute is 85 kg. (187lb.).

Part II.

Load Cases.

1101. The air, ground and other forces to be assumed in the individual cases of loading on the sailplane, and specified below are not, as a general rule, in equilibrium with each other. Consequently states of acceleration are produced in the various cases. The inertia forces appropriate to such states and producing the state of equilibrium must be taken into consideration in the strength calculations.

1102. If no specifications are made with regard to certain quantities (such as components of force, angular velocities, etc.) which are necessary for the accurate determination of a load state, these quantities are to be assumed as equal to zero. In special cases only will parameters, which should be assumed to be equal to zero, be specified.

1103. In the loading cases dealt with below the decisive loads in each instance which fix the size of the individual parts of the sailplane (including installations) are those with which the individual parts acquire their most unfavourable loading. (In general the maximum permissible all-up weight is decisive.)

1104. Unless otherwise stated, the loading cases are regarded as safe states of stress (*cf.* 1004).

Section I.

Loading Due to Air Forces.

1110. In the load cases under investigation the air forces to be assumed for the individual structural units (wings, tail unit, etc.) are either given directly with regard to magnitude and direction, or are determined, together with their distribution, from definite data with respect to flying position, and the state of speed or acceleration of the sailplane.

A. Basic Loading Cases.

1120. The basic loading cases are flight conditions in which symmetrical loading and equilibrium of moments are assumed about all axes. In order to keep the cases as simple as possible, the angular velocity in pitch can be assumed to be zero. In order to attain equilibrium in pitch, the elevator angle is to be set so that with the given tail setting, the tail load will be :—

$$P_t = -M'/l_t$$

(for the calculation of the load on the tail unit, the loaded weight and the trim of the aeroplane must be so selected that the absolute maximum load on the tail

unit occurs (*cf.* 1103)). In practice the distance of the c.p. of the tail unit with neutral elevator from the c.g. of the sailplane may be taken for l_t.

1121. In the various basic loading cases, two of the three following fundamental quantities will be available:—

Dynamic pressure ($q = \frac{1}{2}\rho v^2$).

Angle of incidence (α given by C_L of the whole sailplane or of the wing alone).

Air force (P, given by the " total load factor ":—

$$n = P/W \approx (P_w + P_t)/W = n_w + P_t/W$$

or by the " wing load factor "

$$n_w = P_\alpha/W.$$

These quantities are connected by the relation:—

$$P = nW = \overline{C}_L qS$$

or

$$P_w = n_w W = \overline{C}_{Lw} qS$$

(the inertia forces acting on the various component masses, including the components of acceleration due to gravity are obtained by multiplying the weights of the component masses by the total load factor $n = P/W$. Their direction, opposed to the resultant air force on the aeroplane, is determined by C_L and C_D).

1125. I. Nose Dive (so-called *C* Case).

Case 100.

$C_L = 0$.

$q = 5\ W/S$ for Stress Group 1.*

$= 12.5\ W/S$ for Stress Group 2.*

But q is not to be greater than the maximum attainable when using automatically opening brake flaps.

II. Pulling Out.

(*a*) Limiting cases with steady airflow.

1126. 1. With positive lift coefficient (limiting cases *A* and *B*).

Case 105.

$n_w = 3.0$ for Stress Group 1.

$= 4.0$ for Stress Group 2.

C_L wing = maximum lift coefficient, to be put = 1.5 if the exact value is not known.

Case 106.

$n_w = 3.5$.

$q = q$ for Case 100.

2. With negative lift coefficient (limiting case *E*).

Case 110.

$n_w = 2.0$.

C_L wing = maximum negative value to be taken as $= -0.4$ if the true value is not known.

B. Composite Loading Cases.

1140. The composite loading cases differ from the basic loading cases in Part II, Section I, *A*, in that some of the quantities assumed to be zero in the basic

* Stress Group 1 includes all gliders having aspect ratios (b^2/S) not greater than 9 Stress Group 2 includes all other gliders and sailplanes excepting aerobatic types, for which there are as yet no published official requirements.

cases are here different from zero, or that new quantities (such as velocity and direction of gusts) are added in the determination of the state of stress.

I. Action of Gusts.

1141. The load cases due to the action of gusts, dealt with below, occur when a sailplane flies at a definite speed v into an airstream of a velocity v_b which is bounded, without a zone of transition, by the rest of the air imagined as being at rest. If v_b is directed perpendicularly to v and parallel to the plane of symmetry, or if v_b meets the plane of symmetry perpendicularly, α and α' or α_F vary by the angle $\tan^{-1}(v_b/v)$, and in place of an aerodynamical coefficient C, a value approximately of $C+(vb/v)(dC/d\alpha)\eta$ occurs. The coefficient η contained therein is intended to take into consideration the following facts:—The entry of a wing or tail surface of finite chord into the gust and the development of the change of lift takes place in a finite period of time, and during this period of time the sailplane acquires a component of velocity in the direction of the gust.

If v_b is parallel to v the gust entails merely a variation of the pressure head corresponding to the variation of the relative speed at which the air flows past the sailplane.

The parameters given below are divided into two columns, those serving to determine the "initial state" which must be assumed as effective before the setting in of the gust at the left, and those in accordance with the data relative to the actual gust to be assumed on the right.

In the initial states the moments of the air forces are to be assumed as being in equilibrium. On the other hand, owing to the rapid setting-in of the gust forces, the moments produced by gusts relative to the principal axes of the sailplane are to be considered as compensated by the inertia forces alone (and not by operation of control surfaces).

(*a*) Action of Gusts in Unaccelerated Horizontal Flight.

Initial State.	Gust Effect.
$n=1$.	v_b perpendicular to v.
$q=$ max. q on unaccelerated glide.	$v_b=10$ m./s. (33 f.p.s.).
$\rho=\rho_0$.	

1142. 1. Action of Gusts on the Wing Unit.

Initial State.	Gust Effect.
	v_b parallel to plane of symmetry.
	$\eta=0.8$.

As an approximation the wing load factor may be taken as:—

$$n_w=P_w/W\approx[1+q(S/W)(v_b/v)(dC_L/d\alpha)\eta]$$

and accordingly

$$C_L\approx\pm(n_wW/qS)$$

when the same sign must be selected as is assumed by the expression for n_w in the square brackets. Air forces and inertia forces attain their highest values with different values of the total loaded weight.

Initial State.	Gust Effect.
Case 115.	$v_b=+10$ m./s. up (33 f.p.s.).
Case 117.	$v_b=-10$ m./s. down.

1143. 2. Action of Gusts on the horizontal Tail Unit.

Initial State.	Gust Effect.
Zero elevator angle.	v_b parallel to plane of symmetry.
	$\eta=0.6$ (this includes effect of wing downwash).

(The part of the tail loading contributed by the gust can be expressed as

$$P_t=q(v_b/v)(dC_{nt}/d\alpha)\eta.$$

This loading is added to that already necessary for the trim of the sailplane before the gust was encountered.)

	Initial State.	Gust Effect.
Case 119.		$v_b = +10$ m./s. up (33 f.p.s.).
Case 120.		$v_b = -10$ m./s. down.

1144. 3. Action of Gusts on Fin and Rudder.

	Initial State.	Gust Effect.
	Zero rudder angle.	v_b perpendicular to plane of symmetry $= \pm 10$ m./s.
Case 121.		(a) + from starboard.
a and b.		(b) − from port.
		$\eta = 1.0$.

[For the load produced on the fin and rudder it may be assumed that—

$$P_f = q\,(v_b/v)\,(dC_{nf}/d\alpha)\,\eta.]$$

II. Operation of Controls.

1150. Whereas in the foregoing load cases, deflections of control surfaces are assumed only to the extent to which they are necessary for the production of the equilibrium of the moments due to the air forces, in the following load cases, the influence of a voluntary operation of the control surfaces is taken into account.

In order to lay down straightforward loading cases for the sailplane as a whole, in each of the following cases an " initial state " is first given to which the more detailed rotational motion of the sailplane, or the control surface or tail loadings are to be added.

(a) Operation of the Ailerons.

1151. With aileron deflection there occurs (1), as a result of the variation in the lift coefficient entailed, an air force moment M_{x1} corresponding to the angle of deflection of the ailerons is produced; (2) as a result of the rotation of the aeroplane about the longitudinal axis and of the variation of the incidence of the individual wing cross-sections caused thereby, an air force moment M_{x2} opposed to the moment M_{x1} is produced.

The resultant air force moment about the longitudinal axis is

$$M_x = M_{x1} + M_{x2}$$

with the corresponding angular acceleration

$$dp/dt = M_x/A \qquad p = \text{angular velocity in roll.}$$

For the following cases with constant and accelerated turning, the initial state is given by:—

$$q = 2.5\ W/S \text{ for Stress Group 1.}$$
$$= 6.25\ W/S \text{ for Stress Group 2.}$$
$$C_L \text{ (wing)} = 0.20 \text{ for Stress Group 1.}$$
$$= 0.12 \text{ for Stress Group 2.}$$

1. Uniform Rotation.

1152. To the initial state are to be added the air forces of an unaccelerated rolling motion (having such an angular velocity p, that $M_x = 0$ and also $dp/dt = 0$). See Part III.

Case 135.	(a) Port down.
a and b.	Starboard up.
Aileron angle $= 15°$.	(b) Port up.
	Starboard down.

2. ACCELERATED ROTATION.

1153. To the initial state the following aileron loadings are to be added:—

Case 137.

a and *b*.

For Stress Group 1: 25 kg./m.^{2} of aileron area (5.1 lb./ft.^{2}).
For Stress Group 2: 37 kg./m.^{2} of aileron area (7.1 lb./ft.^{2}).
(*a*) Upwards on port side, downwards on starboard.
(*b*) Downwards on port side, upwards on starboard.
($p=0$, $dp/dt=M_x/A$. Air load distribution, see Part III.)

(*b*) OPERATION OF THE ELEVATOR OR RUDDER.

1155. In the following loading cases definite loadings for the tail are laid down. In so far as the proportion of the load falling on the elevator or rudder is not definitely laid down, data is given with regard to the fin or tail setting to be assumed and from this, in conjunction with the given initial state, there results a definite elevator or rudder angle and thus a definite load distribution over the vertical or horizontal tail units (see Part III).

The following data on the loadings to be added are based on the following values:—

Loadings per unit area of tailplane and elevator or fin and rudder:—

Stress Group 1: 50 kg./m.^{2} (10.2 lb./ft.^{2}).
Stress Group 2: 75 kg./m.^{2} (15.4 lb./ft.^{2}).

In the following cases on the operation of the rudder and elevator, the initial state is given by:—

$n-1$.
$q=$maximum q on unaccelerated glide.

1156. 1. Tailplane and Elevator.

Case 140.

Zero tailplane incidence and above tail loading, upwards.

Case 141.

Zero tailplane incidence and above tail loading, downwards.

Case 142.

Zero elevator load, and half the above loading on the tailplane, upwards.

Case 143.

Zero elevator load, and half the above loading on the tailplane, downwards.

1157. 2. Fin and Rudder.

Case 144.

a and *b*.

Zero fin incidence and above loading (*a*) from starboard and (*b*) from port.

Case 145.

a and *b*.

Zero rudder load and 0.33 times the above loading on fin (*a*) from starboard and (*b*) from port.

III. TOWING.

1158. Winch Towing (so-called Case W).

The sailplane is towed, and by means of elevator angle a definite flight attitude attained. From the simplified equilibrium conditions for the moments about the attachment point of the towing force:—

$$P_t(l_t+l_1)+P_w l_2-Wl_1=0$$

if l_1 and l_2 are about equal for the air loads acting on the wings and with the

addition of an extra factor k to take account of the gust effects and the increase of wind speed with height:—

$$n_w = 1 - k\,(P_t/W)\,\{\,(l_t+l_1)/l_1\,\}$$
$$= 1 - kC_{Lt}q\,(S_t/W)\,\{\,(l_t+l_1)/l_1\,\}$$

Particularly is to be assumed:—

Case 152. q = maximum towing q.
C_{Lt} = maximum negative value.
$k = 1.25$.

IV. Further Loading Cases.

(a) and (b) not yet applied.

(c) Combination of proportions of the maximum loads of the horizontal and vertical tail units.

1180. In the following cases simultaneous action of loads on the horizontal and vertical tail units is assumed. In these the maximum upwards and downwards tail loads must be determined from Cases 100, 105, 106, 110, 140 and 141. The assumptions to be made are:—

Case 165.
a and b.
Horizontal tail load = 0.75 of maximum value upwards.
Vertical tail load = ±0.75 of the load in case 144.
(a) + from starboard and (b) − from port.

Case 166.
a and b.
Horizontal tail load = 0.75 of maximum negative value (downwards).
Vertical tail load = ±0.75 of the load in case 144.
(a) + from starboard and (b) − from port.

(d) Asymmetrical additional load with originally symmetrical load cases.

1185. In the following cases, additional air forces are assumed as being produced on the wing and horizontal tail unit respectively in such a manner that, with the originally symmetrical load cases concerned, the absolute values of the air forces to be assumed on one symmetrical half of the wing or tail unit with invariable distribution are reduced by 30 per cent. Production of equilibrium by inertia forces is assumed.

In cases 170, 175, 180 and 185 the absolute *larger* air force acts:—
(a) on the starboard, (b) on the port side.

1186. With 30 per cent. reduction of the absolute value of the air force on one side of the wing unit, that load case is effective (considering cases 105, 106, 110, 115, 117, 152) in which the air force on the wing unit assumes its maximum

Case 170.
a and b.
Positive value (upwards).

Case 175.
a and b.
Negative value (downwards).

1187. With 30 per cent. reduction of the absolute value of the air force on one side of the tail unit, that load case is effective (considering cases 100, 105, 106, 110, 115,* 119, 120, 140, 141, 152) in which the air force assumes its maximum

Case 180.
a and b.
Positive value (upwards).

Case 185.
a and b.
Negative value (downwards).

* In the case of the action of gusts on the wing unit, the air force of the initial state acts on the horizontal tail unit.

Section II.

Loading Due to Ground Forces.

1210. In the following loading cases the position and direction of the ground forces acting on the sailplane are considered with reference either to the sailplane itself or to the ground. Unless other data than those specified below are given in the various load cases, the following assumptions are to be made when carrying out the strength calculations:—

The sailplane rests with wheels and tailskid (or main skid) on the ground, the wheels and tailskid (or main skid) being elastically deformed in accordance with the forces assumed in the various load cases. In general, calculation may be made, also, for the safe forces multiplied by the factors of safety (*cf.* 1004 to 1015) with those states of elastic deformation appropriate to the *safe* loads assumed in the various load cases.

The lateral axis of the sailplane is parallel to the ground.

In the case of sailplanes having wheels, these are assumed unbraked. The component of a ground force, lying in the plane of the wheel applied to the wheel passes through the centre of the wheel. For sailplanes with main skids, the point of application of the resultant impact load is given in each loading case.

(In the various loading cases equilibrium is established by inertia loads.)

1220. In the following cases the centrifugal forces resulting from the angular velocity caused by eccentric impact may be neglected.

A. Landing.

I. Symmetrical Landing Cases.

1224. The individual impact loads on the wheels or skid are parallel to the plane of symmetry.

1225. (*a*) Impact on the main undercarriage or main skid.

Case 200.

$$P = 4\ W \text{ for Stress Group 1}$$
$$= 3\ W \text{ for Stress Group 2}$$

perpendicular to the ground, passing through the shock absorbers (rubber buffers) on sailplanes with main skids, when the shock absorbers are for the purpose of taking vertical impact loads.

Case 202.

$$P = 4\ W \text{ for Stress Group 1}$$
$$= 3\ W \text{ for Stress Group 2}$$

directed at 45° to the longitudinal axis of the sailplane, rearwards; for sailplanes with main skids, to pass through the most forward point suitable for the application of oblique loads.

II. Asymmetrical Landing Cases.

1227. (*a*) Impact on the main undercarriage or main skid (yawed landing).

Case 221.

a and *b*.

P (sideways) $= \pm 0.5\ W$. (*a*) + from starboard. (*b*) − from port.

Line of application through point given in Case 200.

For sailplanes with wheels or pair of skids, port and starboard, the load is to be taken

(*a*) On the starboard side.

(*b*) On the port side.

1228. (*b*) Impact of tail skid (yawed landing).

Case 222.

a and *b*.

$$P \text{ (sideways)} = \pm 25\ b/l' \text{ (kg.) or } \pm 55\ b/l' \text{ (lb.)},$$

where b = maximum wing span.

l' = distance from tailskid ground contact point to the point of application of impact load in case 200.

(*a*) + from starboard.

(*b*) − from port.

1229. (*c*) Impact on Wing Tip (Rotating Landing).

Case 223.

a and *b*.

$P = -50$ kg. (-110lb.) at wing tip directed aft.

(*a*) On port.

(*b*) On starboard.

B. Taxying, Towing, Take-off.

I. Symmetrical Loading.

(*a*) Taxying. (*b*) Towing on normal aerodromes: No requirements.

1237. (*c*) Take-off.

Case 245.

$P = -500$ kg. ($-1{,}100$lb.) forwards, applied at starting hook.

$P = -500$ kg. ($-1{,}100$lb.) rearwards, applied at the rear holding fitting.

Case 246.

$P = +500$ kg. ($+1{,}100$lb.) upwards, applied on the casting-off fitting for the starting cable (see also Case 265).

Case 247.

$P = -500$ kg. ($-1{,}100$lb.) downwards, applied on the casting-off fitting for the starting cable.

II. Asymmetrical Loading.

1248. (*c*) Take-off.

Case 265.

$P = 500$ kg. (1,100lb.) as a single load in every direction parallel to the rolling plane, applied on the casting-off fitting for the starting cable.

Section III.

Loading Due to Water Loads.

No requirements.

Section IV.

Loading Due to Hand and Foot Forces and Other Loads.

A. Loads on Control Components.

1420. The forces and moments to be assumed for the control components may, under normal conditions, be applied for a short period by hand and foot forces. From these control loads and moments are obtained in general other loadings (rigidly fixed control surfaces being assumed) in the control circuits than those obtained in Part II with the stick, handwheel and rudder pedals rigidly fixed.

1421. The following hand and foot loads are to be used for proportioning the control system from the point of application of the hand or foot loads, up to and including the control surface stops.

1422. For the proportioning of the control members between the control surface lever and the stop, 1.3 times the safe loadings for the rudder, elevator and aileron respectively as given in Part II, Section I, are to be used.

1425. In the following cases, in the absence of more exact data with regard to the direction of the forces to be applied, the least favourable direction must be selected in each case.

In the cases marked (*a*) and (*b*), case (*a*) denotes :—

Application of force from the starboard side directed towards the plane of symmetry, or

Application of force (or by means of the right foot) on the starboard side, parallel to the plane of symmetry, or

Application of moment in the anti-clockwise direction (facing direction of flight).

I. Application of Force on One Control Unit.

(*a*) Hand load.

1426. 1. Basic cases.

Case 400.

Operation of elevator

$P = 25$ kg. (55lb.) parallel to plane of symmetry on the stick.

Case 402.

a and *b*.

Operation of aileron

$P = 25$ kg. (55lb.) perpendicular to plane of symmetry, on the stick.

1427. 2. Composite cases. No requirements.

1430. (*b*) Foot load.

Case 420.

a and *b*.

Operation of rudder by one foot

$P = 50$ kg. (110lb.).

Case 421.

Counter support with both feet

$P = 50$ kg. (110lb.) per foot.

E. Inertia Forces on Seats.

1470. The forces specified in load cases 475 to 480 represent the inertia forces of persons (including the proportions of acceleration due to gravity) produced in certain states of acceleration on the safety belt or directly on the seats or backs of seats. In the absence of other data relating to the point of application of such a force it is to be assumed that this force is applied at the centre of a circle, of radius 0.2 m. (0.66ft.) lying in the plane of symmetry of the seat concerned and in contact with the back and the padding (compressed) of the seat. The various details apply also to seats not fitted in the direction of flight.

When in individual cases the force to be applied by the occupant is taken up through the medium of a waist belt or shoulder strap, this force must be resolved into two components, one lying in the plane of the safety belt passing round the occupant and transmitted further by this belt and the second perpendicular to the surface of contact of the body with the seat or back and absorbed by the latter.

When the horizontal forces specified below are applied transversely to the direction of sitting and are transmitted further by safety belts, the direction of the belt must be assumed as deflected to the side, at the points of attachment of the belt in the sense of the direction of the force in such a manner that its projection in the horizontal plane forms an angle of 30° with the force.

When, in the details relative to the forces to be applied, reference is made to the weight of a person, the latter must be applied in accordance with the details under 1080.

Case 475.

Exerted by the occupant on the waist belt and seat:—

$$P = -560 \text{ kg. } (1{,}230\text{lb.}) \text{ forwards.}$$

Case 476.

Exerted by the occupant on shoulder strap and seat:—

$$P = -350 \text{ kg. } (770\text{lb.}) \text{ forwards.}$$

Point of application as opposed to case 475, displaced 0.25 m. (0.82ft.) upwards.

Case 477.

Exerted by the occupant on the back of the seat:—

$P = +300$ kg. $(+660\text{lb.})$ backwards, only on pilot's seats of sailplanes not designed for catapult launching.

$= +400$ kg. $(+880\text{lb.})$ backwards, on each seat, including pilot's seat, for sailplanes designed for catapult launching.

Case 478.

a and *b*.

Exerted by the occupant on waist belt and seat:—

$$P = \pm 100 \text{ kg. } (\pm 220\text{lb.}) \text{ sideways.}$$

(*a*) + from starboard, (*b*) − from port.

Case 479.

Exerted by the occupant on the seat:—

$P = W_p (P_z/W)_{max}$ downwards, where $(P_z/W)_{max}$ is the highest positive value of the ratio (P_z/W) for cases 100 to 399. P_z is the component in the z direction of the resultant force on the sailplane.

Case 480.

Exerted by the occupant on the waistbelt and back of seat:—

$P = W_p (P_z/W)_{min}$ upwards, where $(P_z/W)_{min}$ is the highest negative value of the ratio (P_z/W) for cases 100 to 399.

1480. *F.* Handling Loads.

Case 490.

$$P = 7.5 \text{ kg. } (16.5\text{lb.})$$

as handling load at every position of the aeroplane where the application of handling loads is to be considered, the force assumed to be acting in the most unfavourable direction.

Part III.

Particulars Relative to the Carrying Out of Strength Calculations.

1500. The formulæ and methods given below may be applied for carrying out approximate strength calculations. When they are to be used also for the final strength calculations, it must be determined in each individual case whether the conditions presented correspond sufficiently to the assumptions in the various particulars.

A. Air Forces and Distribution of Air Forces.

1505. In the determination of the lift forces and the distribution of lift on wings and tail surfaces of ordinary plan and profile shapes, the data supplied under items 1510 to 1535 may be employed if more exact investigations, such as wind channel measurements or more detailed calculations, are not regarded as necessary.

1506. The differentials dC_L, $d\alpha$, $d\beta$, occurring in a number of formulæ may be replaced by finite quantities.

I. Distribution of the Air Force Over the Span of the Wing and the Tail Unit.

1510. When the distribution of the air forces in the direction of the span of the surface concerned is not determined by experiment, a calculation may be made of the distribution of the lift on the basis of the vortex theory as a function of the plan form of the surface and of the variation of the angle of incidence along the span. In each case it must be ascertained whether any departure from the distribution of the air force such as may be brought about, for instance, by diversion of the flow, leads to less favourable stresses in the wing or tail surface. This applies particularly to wings or tail surfaces with tapered plans (*cf.* also 1525 and 1526).

1511. In the case of wings or tail surfaces in which the twist in both the unloaded and the loaded state is unimportant, and the plan of which differs only in an unimportant degree from a rectangle or an ellipse, the following approximate assumptions (*a*) and (*b*) may be made as a general rule in flight cases where the angular velocity in roll is zero. The rating of each individual part must be based always on the more unfavourable of the two assumptions (*cf.* also 1525 and 1526).

(*a*) $C_L \cdot q$ is constant along the span.

(*b*) $C_L \cdot q$ is constant along the span as far as that cross-section which is situated at a distance equal to the mean chord of the surface from the tip (chord of the rectangular surface of the same area and the same chord as the given surface). From this cross-section to the tip, $C_L \cdot q$ diminishes linearly by 50 per cent.

II. Effect of Variations of Incidence and of Deflection of the Control Surface.

(*a*) Variation of lift with variation of incidence.

1520. The variation of the lift with variation of the angle of incidence may be determined by the following formula (*cf.* Table 8 and Fig. 29):—

$$dC_L/d\alpha = 2\pi\zeta/(1 + 2A\zeta)$$

in which $A = S/b^2$ and $\zeta = 0.88$.

(*b*) Variation of the lift and of the distribution of lift over the wing span when operating controls.

Table 8.

Numerical values of $dC_L/d\alpha$ as a function of S/b^2.

S/b^2	0.500	0.475	0.450	0.425	0.400	0.375	0.350	0.325	
$dC_L/d\alpha$	2.94	3.01	3.09	3.16	3.25	3.33	3.42	3.52	
S/b^2	0.300	0.275	0.250	0.225	0.200	0.175	0.150	0.125	0.100
$dC_L/d\alpha$	3.62	3.73	3.84	3.96	4.09	4.23	4.38	4.54	4.71

Note.—$\zeta = 0.88$.

Table 9.

Numerical values of $d\alpha/d\beta$ as a function of c_r/c.

c_r/c	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
$d\alpha/d\beta$	0.20	0.40	0.48	0.55	0.61	0.66	0.71	0.75	0.79	0.83

1525. The variation, due to deflection of the control surface, of the lift acting on a profile with control flaps (ailerons) may, as a general rule, be determined by the following formulæ:—

$$dC_L/d\beta = (dC_L/d\alpha)\,(d\alpha/d\beta)$$

in which

$$d\alpha/d\beta = (\pi - \phi + \sin\phi)/\pi \qquad \phi = \cos^{-1}(2\,C_r/C - 1)$$
$$\approx (4/\pi)\,\{\,1 - \tfrac{1}{6}\,(C_r/C)\,\}\,\sqrt{(C_r/C)}$$

(*cf* Table 9 and Fig. 30).

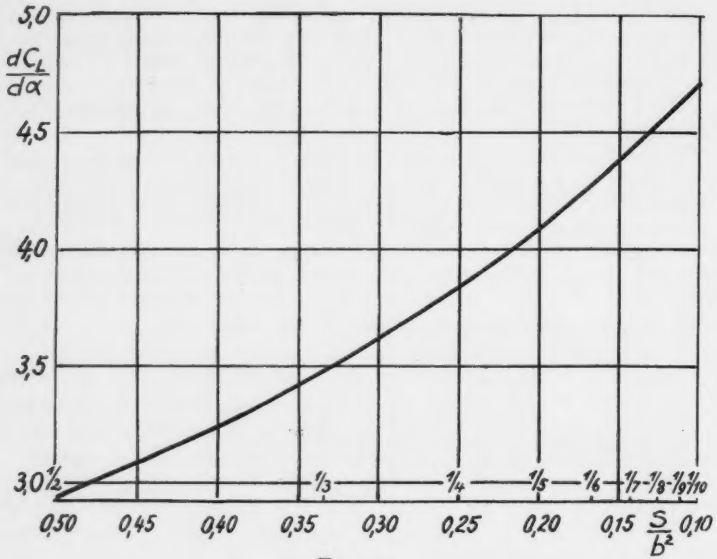


FIG. 29.
Values of $dC_L/d\alpha$ plotted against aspect ratio.

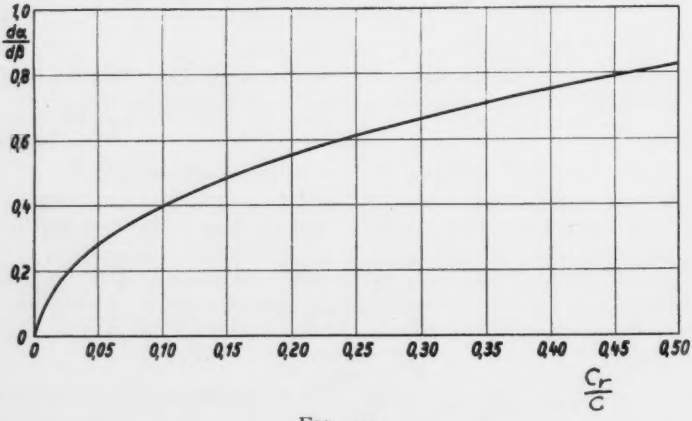


FIG. 30.
Values of $d\alpha/d\beta$ plotted against c_r/c.

Taking into account the reciprocal influences* of the individual sections of a wing, the variation of the distribution of the lift along the span, due to the

* The approximation method given below has been checked for wing forms similar to those represented in Fig. 32a.

deflection of the control surface, may be determined by the graph shown in Fig. 31. In the term $dC_L/d\alpha$ of the formula for $dC_L/d\beta$, the value A_{fq} (*cf.* Figs. 32*a*, 32*b*) must be assumed for A (for influence of velocity of roll see 1526).

1526. The variation of the lift distribution over the wing span due to the angular velocity in roll, supplementary to the variation of the lift distribution under 1525 may be determined by the formula :—

$$dC_L/d\omega = (dC_L/d\alpha)\,(d\alpha/d\omega)$$

in which $d\alpha/d\omega$ approx. $= y/v$ and $dC_L/d\alpha$ is determined by the formula in 1520, where, taking into account the reciprocal influence of the individual sections of the wing, a value A_y as a function of y, in accordance with the following formula is assumed for A at every position y :—

$$A_y = \tfrac{1}{2}\,\Delta_y\,\{\,(2\,A_0 + \Delta_y)/(A_0 + \Delta_y)\,\}$$

where

$$\Delta_y = S_y/\pi\,(\tfrac{1}{2}\,b - |y|)^2.$$

III. Distribution of Air Force Over the Chord of the Wing and of the Tail Unit.

1530. The following data may be used for the calculation of the distribution of the air force over sections of the wing and of the tail unit with the control surface both non-deflected and deflected. They give the distribution of the resultant air forces due to suction and pressure as a function of x^*.

The data are not sufficient when separate calculation of the pressures exerted on the upper and under sides is considered to be necessary, when the section mean camber line is s-shaped, or when other unusual cases are presented.

1531. Introducing the functions f_a, f_m, f_β, defined below and shown in Figs. 33, 34, 35, the following formula is applied :—

$$p\,(x^*) = q\,(C_L \cdot f_a + C_{M0} \cdot f_m + \beta \cdot f_\beta)$$

(the last term within the brackets applied only to sections in the region of the control surfaces), in which :—

q = dynamic pressure.

β = angle of deflection of the control surface.

C_L = lift coefficient of the profile at the incidence and deflection of control surface at the time concerned, allowing for an eventual angular velocity in roll of the appropriate wing or control surface (*cf.* 1526). If $C_L\,(\beta = 0)$ is the lift coefficient of the profile with non-deflected control surface in accordance with 1525 it must be assumed that :—

$$C_L = C_L\,(\beta = 0) + \beta\,(dC_L/d\beta)$$

C_{M0} = moment coefficient for the profile with non-deflected ailerons at the angle of incidence for which $C_L = 0$.

The three terms in the bracketed expression in the formula for $p\,(x^*)$ are defined below (it is assumed that $dC_M/dC_L = 0.25$ as is the case for most sections).

$C_L \cdot f_a$ = distribution of lift over a straight line section (without deflection of control surface) set at such an angle to the wind that a lift corresponding to the actually effective lift coefficient,

$$C_L = C_L\,(\beta = 0) + \beta\,(dC_L/d\beta)$$

is produced (see Fig. 38).

$C_{M0} \cdot f_m$ = distribution of lift over a thin parabolic section symmetrical to the perpendicular to the centre of the chord, set at such an angle to the wind that no lift is produced, and the curvature of which is so selected, that with this direction of incident wind an air force moment corresponding to the coefficient C_{M0} (see above) is produced (see Fig. 34).

$\beta \cdot f_\beta$ = distribution of lift over a straight line section with control surface deflected at an angle β, and the same characteristic value $\phi = \cos^{-1}$

$(2\,c_r/c - 1)$ as obtained with the wing section actually presented, and in a wind approaching at such an angle that no lift is produced (see Fig. 35).

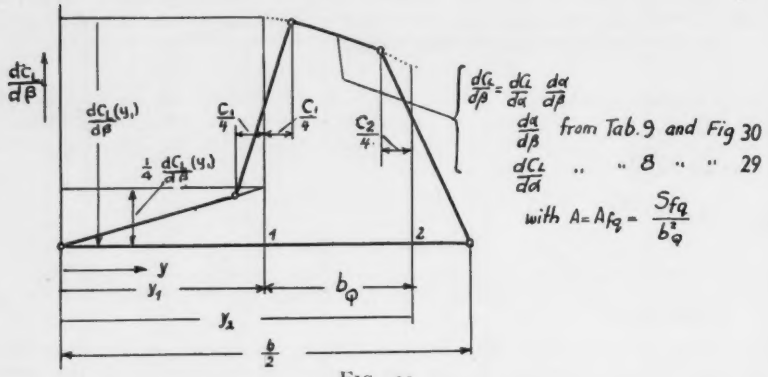
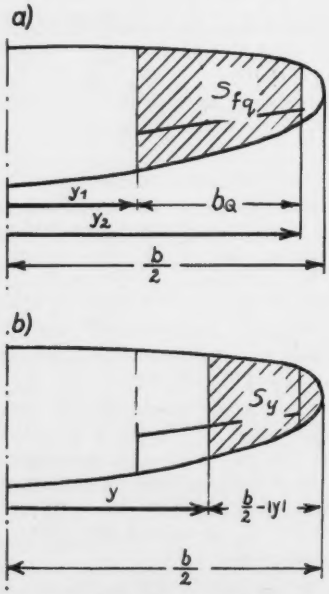


FIG. 31.

$dC_L/d\beta$ along the wing span, taking into account the reciprocal influence of the individual wing sections. (Range of aileron from y_1 to y_2, c_1 and c_2, wing chords at y_1 and y_2.)



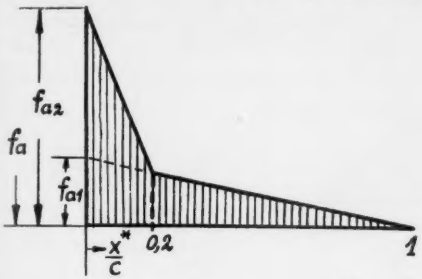
FIGS. 32*a* AND 32*b*.
Notations.

The three distribution functions are shown approximately in Figs. 33, 34, 35, by straight lines, which are particular values of the ordinate and are joined to each other at particular points along the chord.

In the special case of infinitesimal control surface load ($p=0$ in cases 142, 143 and 145) the bracketed expression in the formula for $p(x^*)$ gives the air load distribution shown in Fig. 36.

1532. As a general rule, with the distribution of the air force $p(x^*)$ according to 1531, the air force moment with reference to the nose of the section is:—

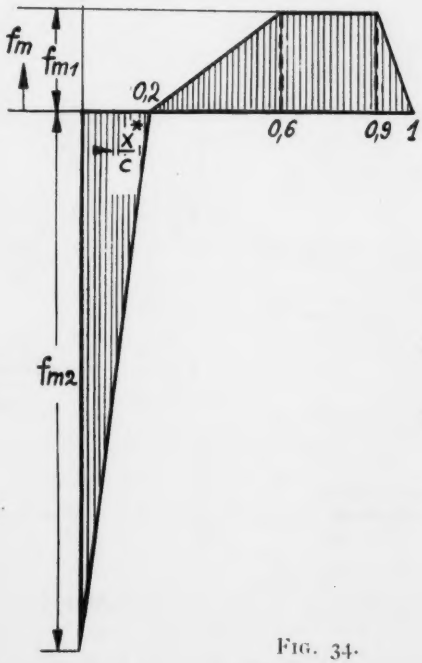
$$m = qc^2 (0.25\, C_L + C_{M0} + \beta C'_M)$$



$f_{a1} = 1,38$

$f_{a2} = 4,5$

FIG. 33.
Graph of f_a.



$f_{m1} = 2,96$

$f_{m2} = 16,3$

FIG. 34.
Graph of f_m.

where

$C'_M = 0.443 \sin\phi - 0.222 \sin 2\phi$ may be assumed.

(Moment with reference to position $x^* = 0.25\, c$

$$m_{0.25\,c} = qc^2 (C_{M0} + \beta C'_M)$$

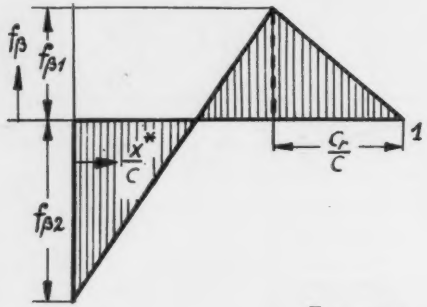
independent of C_L.)

TABLE 10.

Numerical values of C'_M as a function of c_r/c.

c_r/c	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
C'_M	0.37	0.48	0.54	0.57	0.58	0.57	0.55	0.52	0.48	0.44	0.40	0.35

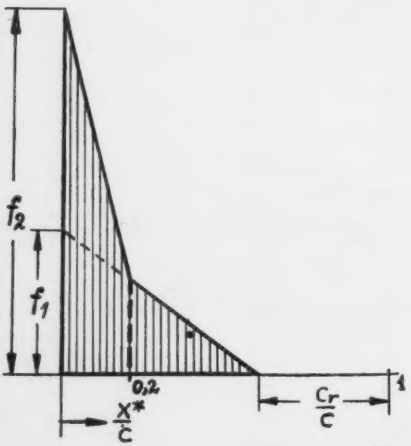
1535. If the leading edge of the aileron projects from the wing section at the angular velocity to be assumed in the calculation in order to allow for the high loading at the leading edge of the aileron, those air forces must be taken as a



$$f_{\beta 1} = 6\, c'_m$$

$$f_{\beta 2} = \frac{6\, c'_m}{1 - \frac{c_r}{c}}$$

FIG. 35.
Graph of f_β.



$$f_1 = \frac{1{,}38}{1 - \frac{c_r}{c}};$$

$$f_2 = \frac{4{,}5 - 3{,}12\ \frac{c_r}{c}}{1 - \frac{c_r}{c}}$$

FIG. 36.
Air load distribution function in the case of infinitesimal control surface loading.

basis for the calculation of the strength of the aileron which are produced if the aileron is regarded as a " free flying " wing.

B. FLUTTER OF WING AND CONTROL SURFACES.

1540. The mean chord c_x of a wing or control surface to be assumed in the reduction of a frequency according to 1078 may be regarded as sufficiently safe

if selected as equal to the smallest of the three values obtained by the following formula :—

$$c_m = \int (f(s)^2\, c(s)^3\, ds) / (f(s)^2\, c(s)^2\, ds)$$

in wnich :—

s = the co-ordinate of a cross-section of the wing or control surface concerned, measured along the line of intersection of the wing or control surface with the rolling plane or planes parallel to the latter.

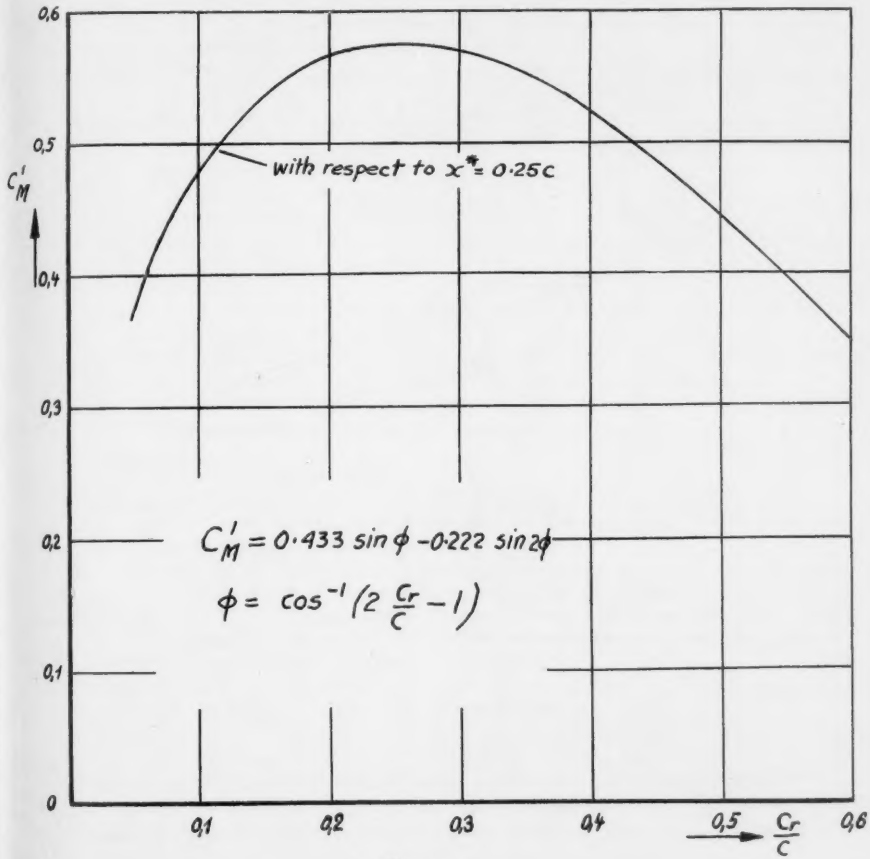


FIG. 37.

C'_M plotted against c_r/c.

$c(s)$ = the chord of the wing or control surface measured at the point of intersection with the s co-ordinate.

$f(s)$ = the following three quantities at frequency n measured successively at the cross-section with the s co-ordinate :—

1. The ratio of the amplitude of the path perpendicular to the wing or control surface, of the point with $x^* = 0.35\ c$ (see Fig. 38) relative to the chord of the wing.

2. The amplitude of rotation parallel to the plane of the cross-section of the elements of the wing or of the tailplane situated in front of the control surface.
3. The amplitude of rotation parallel to the plane of the cross-section, of the control surface with reference to a fixed system of co-ordinates. The integrals extend to all cross-sections within the region of the control surfaces including any section of the wing or tail surface or, in the absence of control surfaces, to all cross-sections of the wing or tail surface.

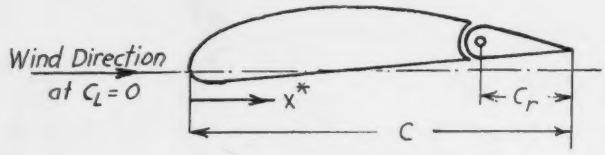
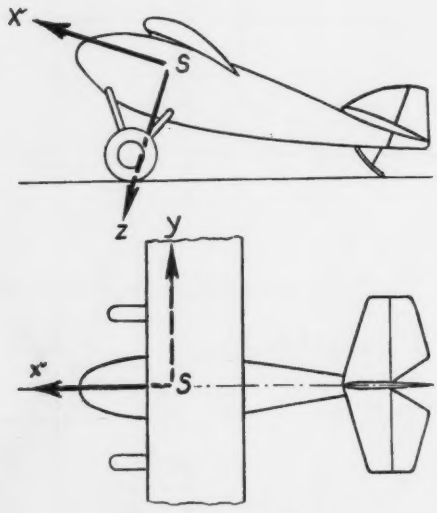


FIG. 38.
Co-ordinate x.*



FIGS. 39*a* AND 39*b*.
Co-ordinates and angles of inclination.
x, y, z = co-ordinates in direction of principal axes of the sailplane.
x_o, y_o = co-ordinates of the point of intersection of the line of the resultant force acting on the sailplane and the xy plane.

LIST OF SYMBOLS.

Those defined in the text or obvious from the context are not included in this list.

b (m. or ft.) = maximum wing span.
C_L = lift coefficient, based on plan wing area.
C_{Lt} = lift coefficient of horizontal tail, based on horizontal tail plan area.
$C'_M = dC_M/d\beta$ where C_M is the moment coefficient of the sailplane, based on the wing area.

C_{Mo} = moment coefficient for a wing section alone with non-deflected flap, at the incidence for zero lift.

C_{nt} = normal force coefficient of the horizontal tail surface, based on the tail area.

C_{nf} = normal force coefficient of the vertical tail surface, based on the fin and rudder area.

S (m.^{2} or ft.^{2}) = wing plan area.

S_{fq} (m.^{2} or ft.^{2}) = area of an aileron and the part of the wing lying in front of it.

S_y (m.^{2} or ft.^{2}) = area of portion of a wing or control surface bounded by the tip of the wing or control surface and the cross-section at a distance y from the plane of symmetry (*cf.* Fig. 32*b*).

W (kg. or lb.) = all-up weight of sailplane used in the strength calculations.

W_p (kg. or lb.) = weight of a person (including parachute).

A (kgms.^{2} or lb. ft. sec.^{2}) = principal moment of inertia relative to the principal axis of the sailplane in the longitudinal direction x. Used in paragraphs 1151 and 1153 only.

Λ = aspect ratio = plan area/span^2.

Λ_{fq} = aspect ratio of a hypothetical wing = S_{fq}/b_Q^2, see Fig. 32*a*.

Λ_y = hypothetical aspect ratio of a wing at a cross-section at a distance y from the plane of symmetry.

j = factor of safety.

l_1 (m. or ft.) = distance from the starting cable attachment at starting hook to the c.g. of the sailplane.

l_2 (m. or ft.) = distance from the starting cable attachment at starting hook to the centre of pressure of the air load on the sailplane.

l_t (m. or ft.) = distance from the c.g. of the sailplane to the centre of pressure of the horizontal tail.

M (kgm. or ft. lb.) = moment of the forces acting on the sailplane relative to the c.g. of the sailplane.

M_x (kgm. or ft. lb.) = component of M with respect to the x axis.

M_{x1} (kgm. or ft. lb.) = air force moment about the longitudinal axis due to a displacement of the ailerons.

M_{x2} (kgm. or ft. lb.) = air force moment about the longitudinal axis due to a rotary motion of the sailplane about the longitudinal axis (rolling).

M' (kgm. or ft. lb.) = moment of the air forces acting on the wing unit, fuselage, undercarriage, etc., but not on the elevator unit, relative to the transverse axis y of the sailplane.

n = load factor of the sailplane (ratio of the resultant of all forces acting on the sailplane to the total all-up weight) $n = P/W$.

n_w = load factor of the wing unit (ratio of the resultant of all forces acting on the wing unit to the total all-up weight) $n_w = P_w/W$.

P (kg. or lb.) = force. Resultant of all forces acting on the sailplane.

P_x, P_y, P_z (kg. or lb.) = components of P with respect to the x, y, z axes.

P_t (kg. or lb.) = air force on horizontal tail unit.

P_f (kg. or lb.) = air force on vertical tail unit.

P_w (kg. or lb.) = air force on wing.

q (kg./m.^{2} or lb./ft.^{2}) = dynamic pressure, $q = \frac{1}{2}\rho v^2$.

c (m. or ft.) = wing or control surface chord (see Fig. 38).

c_m (m. or ft.) = mean wing or control surface chord.

c_r (m. or ft.) = chord of control surface, in the case of control surfaces with wing or fixed surface situated in front, measured from the axis of rotation of the control surface to the trailing edge of the control surface (see Fig. 38).

v (m./s. or ft./sec.) = air speed.

v_b (m./s. or ft./sec.) = gust speed.

x, y, z (m. or ft.) = co-ordinates in the direction of the main axes of inertia of the sailplane, longitudinal, transverse and normal axes (see Fig. 39, right hand system).

x^* (m. or ft.) = co-ordinate along the direction of zero lift of a section, measured from the leading edge of the section.

α = angle of incidence of a wing or empennage with respect to the wind direction.

α' = angle of incidence of the tailplane.

α_F = angle of incidence of the fin.

α_w = angle of incidence of the wing.

β = angle of deflection of control surface.

ζ = coefficient for making allowance for the difference between the measured and calculated values for $dC_L/d\alpha$.

η = coefficient of gust effect.

ρ (kgs.^{2}/m.^{4} or slug/cu. ft.) = air density. ρ_0 (sea level) = 0.00238 slug/cu. ft.

ω (1/sec.) = angular velocity.

Rules of Signs.

Unless otherwise indicated, the following are regarded as positive:—

The components of velocities, when directed in the sense of the positive co-ordinate axes, x, y, z, or X, Y, Z.

The components of angular velocities, when directed in the sense of the positive rotations xy, yz, zx, or XY, YZ, ZX.

The components of forces and accelerations, when directed opposite to the positive co-ordinate axes, x, y, z, or X, Y, Z.*

The components of moments, when directed opposite to the positive rotations xy, yz, zx, or XY, YZ, ZX.*

Angles of incidence when brought about by the aeroplane being turned out of the initial position in the sense of the positive rotations xy, yz, zx.

Control surface deflections, when they are turned in the direction of positive incidence.

* Accelerations and angular accelerations are thus obtained which are equal and opposite to the derivatives of velocity or angular velocity with relation to time.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 57. JULY, 1938.

The Rôle of Meteorology in Gas Attacks. (Meteorologia and Hydrologia, U.S.S.R., No. 4, April, 1938, pp. 72-3.) (57/1 U.S.S.R.)

The efficiency of a chemical attack, *i.e.*, the concentration of the poison gas in a given locality depends markedly on the strength of air currents. The vertical distribution of the air temperature at the time of attack is thus of great importance. The value of the ground temperature, however, also affects the results, since it affects the rate of evaporation of the liquid chemical. Certain substances require a low temperature, since otherwise they would evaporate too quickly, whilst chemicals with an inherently small vapour pressure are favoured by a high ground temperature. Another important factor is the moisture content of the air. Thus phosgene is decomposed by rain whilst chloro-picrine is only little affected by water. A knowledge of atmospheric conditions thus narrows down the number of substances which can be used with effect, and also indicates when conditions are clearly impossible for chemical attack. It is thought that such information will be of great importance in the defence of populated districts.

The Defensive Armament of General Purpose Aircraft and the Offensive Armament of the Intercepter Fighter. (C. Brissot, Rev. de l'Arm. de l'Air, No. 104, March, 1938, pp. 269-284.) (57/2 France.)

General purpose aircraft are intended for bombardment, combat and reconnaissance and are designated in France by the letters B.C.R. (from the initials).

As they operate well within enemy territory, they are liable to strong attack. A proper defence necessitates at least three firing posts and the weight of armament together with the increased air resistance of the turrets presents a great problem, if bomb load and range are not to be deleteriously affected. The author concludes that the defensive armament of such machines will at least weigh 1 ton and thus will necessitate a relatively heavy machine. Although the intercepter fighter will be operating near its base, and thus require less fuel, the gun armament must be heavy. In the opinion of the author, both fixed and mobile guns should be fitted. This means that the intercepter, in order to fulfil its mission, must be a two- or three-seater and correspondingly heavy.

Apart from a narrow zone near the front lines, the future aerial combat will thus be between machines of relatively large size, the winner being the aircraft fitted with the more powerful guns.

Detection of Aircraft by Short Wireless Waves. (French Patent 809,612 by the Telefunken, Ltd.) (Rev. de l'Arm. de l'Air, No. 104, March, 1938, pp. 350-1.) (57/3 Germany.)

Two beams of ultra short wireless waves of the same wave length are directed vertically upwards so as to produce a field of interference. An aircraft entering this field will reflect the waves and the frequency of the modulation reaching a parabolic receiver placed on the ground at some distance from the emitting station will depend on the speed of the aircraft and the width of the interference fringes.

This simple arrangement will obviously fail if the aircraft is travelling along a fringe and does not cut it. This difficulty can, however, be overcome by using three emitting stations giving a three dimensional fringe system.

The French review points out two difficulties with this method of detection:

(*a*) in order to receive a modulated tone of reasonable frequency, the spacing of the fringe (*i.e.*, the wave length utilised) must be small.

(*b*) small spacing means that the aircraft covers a large number of fringes simultaneously and this may affect the modulation.

Bombing Operations in the Zone of the Interior. (R. B. Colton, Coast Artillery Journal, No. 3, May-June, 1938, pp. 163-9.) (57/4 U.S.A.)

1. Day and night bombing under conditions of broken or poor visibility will be undertaken, the attacks being finally limited to those weather conditions that are found by experience not to produce excessive casualties to the bombers.

2. Reprisals will not stop bombing operations.

3. The operations of land, sea and air forces will not afford much protection to the zone of the interior during the first and critical days of war. In the later stages of a war, field operations will furnish some protection but this in itself will not be enough.

4. Fighter aviation and A.A. artillery are equally valuable in protecting the zone of the interior and are complementary rather than competitive. Both are essential and effective.

5. As in the world war, the bomber can be greatly hindered, but cannot be stopped until the enemy as a whole has been definitely defeated.

Air Power and Troop Movement. (T. R. Phillips, Coast Artillery Journal, No. 3, May-June, 1938, pp. 179-87.) (57/5 U.S.A.)

In comparison with movements by marching, motor transport offers a greater choice of concealment in bivouac, greater secrecy because the road time is reduced, greater dispersion to minimise air attack, greater speed to take advantage of the time-delay factor between observation and attack, greater flexibility in speed, movement in a fraction of the time of foot troops, and delivery of fresh troops instead of tired troops at the end of the march. Motors furnish the answer to the air threat against troop movement. Through them can be regained the secrecy and chance of surprise that foot movements have lost. The army which first learns to use its motors has taken a long step toward victory.

A.A. Trial Shot Slide Rule. (R. W. Russell, Coast Artillery Journal, No. 3, May-June, 1938, pp. 196-9.) (57/6 U.S.A.)

The general purpose of the Russell Slide Rule is to solve rapidly and with the required degree of accuracy, the azimuth of the Trial Shot Point from the distant observing station (O_2), and the angular height of the Trial Shot Point from the O_2 station. These data, obviously, are essential to the proper setting of the observing instrument at the O_2 station. The data having been obtained,

the slide rule provides a means for determining, with speed and within accuracy of five to ten yards, the horizontal range deviations of bursts from the Trial Shot Point for ranges between 1,000 yards and 10,000 yards.

Furthermore, it can be used to advantage for many other purposes, including the solution of anti-aircraft and sea coast gunnery problems. For angular measurements the instrument makes use of the "Mil." However, angular measurements in mils may be readily converted to degrees and hundredths of degrees on it by simple division.

Machine Gun Operation by Means of Compressed Air for Training Purposes. (P. Axelsson, Militar-teknisk Tidsskrift, March, 1938; W.T.M., Vol. 42, No. 5, May, 1938, p. 240.) (57/7 Sweden.)

The author describes a compressed air installation by means of which gun crews can be trained in a simple manner and at less expense than if explosive ammunition is used.

Lead pellets are employed, the effective range being 200 m., the air being at 11 atmospheres. The muzzle velocity is approximately 160 m./sec. The exercises are carried out at distances of the order of 10 m. and special targets cover all methods of employment of this kind of weapon, including A.A. practice.

Lessons of the War in Spain—Efficiency of Bombing Attacks Approaching from the Sea. (C. Rougeron, Inter. Avia., No. 558, 5/7/38, pp. 1-3.) (57/8 France.

The author is of the opinion that modern bombing aircraft will not be able to penetrate more than 90 miles into enemy territory without being detected by the intelligence and messenger corps and engaged by fighters. With equipment of comparable value, the fighter, operating over his own territory, is almost certain to get the better of the bomber. If, however, the bombers approach from the sea, a sufficiently early warning may not be obtainable, especially if the bomber glides in from a high altitude. Thus a bomber flying at 300 m.p.h. at an altitude of 21,000 feet will release his bomb at a distance of approximately three miles from the objective. It is obvious that under these conditions the bomber will be able to evade the dangerous range of A.A. artillery.

Coastal frontiers by their very nature are provided with great centres of population and other targets of importance which are thus extremely vulnerable to an attack from the sea.

In the words of the author: "Attacks of this type are almost as safe as simple commercial transport flights."

Possibilities of Modern Warfare. (A. Chiavarini, Rev. de l'Arm. de l'Air, No. 107, June, 1938, pp. 697-99.) (57/9 France.)

An essential part of Napoleonic strategy was rapidity of movement. By a threat to his lines of communication, the enemy was forced to fight under conditions where his morale had already suffered. The French author proposes to apply the same method under modern conditions by launching an overwhelming air attack on the whole of the enemy territory, without any previous declaration of war. Taking France as an example, he reckons that 60,000 tons of bombs would seriously cripple the whole of its industrial and mobilisation centres.

From this, it follows that a resolute adversary free from moral scruples, possessing several thousand aircraft, might seriously upset the defensive plan of campaign of the land forces.

Whilst Douhet gives a purely defensive role to the land forces and relies on the air force alone defeating the enemy, the author of the present article thus still relies on the army providing the final victory, the air force, however, playing the most important part of paving the way by confusing the enemy and forcing him to fight on a battle ground which is not of his own choosing.

Laminar Boundary Layer Investigations Based on the Theorem of Minimum Dissipation. (R. S. Smith, J. Aeron. Sci., Vol. 5, No. 7, May, 1938, pp. 266-72.) (57/10 U.S.A.)

The classical treatment by Blasius which develops the velocity profile and thickness of the laminar boundary layer on an open air-washed surface under constant pressure, although rigorous as developed, rests upon the rather severe assumption of similitude of velocity profiles. In recent years, both theoretical and experimental evidence has arisen which makes the validity of this assumption open to question. The chief difficulties with the Blasian profile are that it is out of balance with respect to energy, and that it fails to give any indication of flow transition from the laminar to the turbulent phase.

These objections to the Blasius treatment, led the author to examine the possibility of approaching these problems from the standpoint of certain minimum theorems. The present paper is a progress report on only that part of these exploratory studies which has to do with laminar boundary layer under constant pressure and over surfaces of zero curvature.

Measurements with a Half-Pitot Tube. (G. I. Taylor, Proc. Roy. Soc., Series A, Vol. 166, No. 927, 16/6/38, pp. 476-481.) (57/11 Great Britain.)

The use of the half-pitot tube for measuring surface friction of a fluid flowing past a smooth surface was introduced by Stanton in 1920. The half-pitot essentially consists of a very thin rectangular brass plate set at a small distance from the wall. Two side pieces and a back form a small open-ended box, the pressure in which is compared with that of a normal static pressure hole placed in the vicinity.

Under viscous flow, the tangential stress at the surface $=\mu a$ (μ = viscosity, a = rate of shear). The limiting pressure of a very small half-pitot tube must therefore be given by $K\mu a$.

The author describes some experiments with glycerine which indicate that $K = 1.2$.

It is hoped that the problem of determining K theoretically will attract the attention of some mathematician

Interaction of a Fixed Propeller with an Aerofoil. (S. Pivko, Comp. Rend., Vol. 206, No. 20, 16/5/38, pp. 1449-1451.) (57/12 France.)

The author has investigated the aerodynamic forces acting on a model aerofoil placed in the slipstream of a propeller. Lift, drag and moment coefficients are put into non-dimensional force by division by

$$\tfrac{1}{2}\rho DlK^2$$

where D = diameter of propeller.
K = tip speed.
l = chord of wing.

The aerodynamic forces depend on the following parameters:—

(1) l/D.
(2) x/D where x = distance of aerofoil behind propeller.
(3) z/D where z = distance of propeller axis above or below aerofoil.
(4) Relative pitch of airscrew.
(5) Tip speed of airscrew.

The general shape of the wing polars obtained resembles that of wind tunnel results, the resistance becoming however negative if the propeller is placed very close to the wing.

Examples of such diagrams are given for the case:—

$l = 15$ cm. $\quad x/D = \tfrac{1}{2}$.
$D = 30$ cm.
$4/D = 1$ for various values of z/D.

Theoretical and Experimental Contribution to the Problem of Turbulent Velocity Distribution. (J. J. Sommer, Phys. Zeit., Vol. 39, No. 11, 1/6/38, pp. 454-460.) (57/13 Germany.)

The author deals with the mechanism of fully established turbulent motion and investigates the reasons for the change from the laminar velocity distribution. The general treatment is statistical, and a formula for the mean free path of certain elementary fluid particles is developed on reasonable assumption as to the nature of the mutual forces. The results show an effect of the pressure on the velocity profile in the sense that a reduction in pressure causes the turbulent profile to approximate to the laminar shape. Experiments carried out by the author using air at a series of pressures indicate a general agreement with his theoretical conclusions.

Two-Dimensional Subsonic Compressible Flow Past Elliptic Cylinders. (C. Kaplan, N.A.C.A. Report No. 624, 1938.) (57/14 U.S.A.)

The method of Poggi is used to calculate, for perfect fluids, the effect of compressibility upon the flow on the surface of an elliptic cylinder at zero angle of attack and with no circulation. The result is expressed in a closed form and represents a rigorous determination of the velocity of the fluid at the surface of the obstacle in so far as the second approximation is concerned.

Comparison is made with Hooker's treatment of the same problem according to the method of Janzen and Rayleigh and it is found that, for thick elliptic cylinders, the two methods agree very well. The labour of computation is, moreover, considerably reduced by the present solution.

The third approximation to the compressible flow about circular cylinders, including the terms involving the factor $(v_o/c_o)^4$, is also obtained and compared with the result given by Poggi. It is found that the expression given by Poggi is incomplete with regard to the terms containing the factor $(v_o/c_o)^4$.

On the Indeterminacy of the Momentum of an Infinite Fluid. (W. Tollmien, Z.A.M.M., Vol. 18, No. 3, June, 1938, pp. 151-154.) (57/15 Germany.)

The author discusses the resistance of a body undergoing an accelerated motion in an infinite and perfect fluid.

This resistance can be determined from the pressure distribution existing on the surface of the body.

The accelerated motion of the body leads also to a change in momentum of the fluid, and the statement has sometimes been made that the resistance could be calculated from the time variation in the fluid impulse.

The author shows that this argument is fallacious, the value of the impulse obtained depending entirely on the limiting boundary conditions, *i.e.*, as the way we pass from the finite to the infinite liquid.

A similar difficulty arises when the impulse theorem is applied to an aerofoil in steady motion in an infinite fluid.

A Study of the Torque Equilibrium of an "Autogiro" Rotor. (F. J. Bailey, Jr., N.A.C.A. Report No. 623, 1938.) (57/16 U.S.A.)

Two improvements have been made in the method developed in N.A.C.A. Reports Nos. 487 and 591 for the estimation of the inflow velocity required to overcome a given decelerating torque in an "Autogiro" rotor. At low tip speed ratios, where the assumptions necessary for the analytical integrations of the earlier papers are valid, the expressions therein derived are greatly simplified by combining and eliminating terms with a view to minimising the numerical computations required. At high tip speed ratios, by means of charts based on graphical integrations, errors inherent in the assumptions associated with the analytical method are largely eliminated.

The suggested method of estimating the inflow velocity presupposes a knowledge of the decelerating torque acting on the rotor; all available full-scale experimental information on this subject is therefore included.

Full Feathering Propellers. (H. M. McCoy, J. Aeron. Sci., Vol. 5, No. 7, May, 1938, pp. 253-9.) (57/17 U.S.A.)

The ability to stop an engine from rotating in case of an engine failure is, from the safety standpoint, the greatest asset of the full-feathering propeller. In addition, recent flight tests with twin-engined aeroplanes equipped with feathering propellers have shown the definite improvement that can be obtained in all phases of single-engined performance, and in aeroplane control, stability, and also freedom from vibration, from feathering the inactive propeller.

Performance figures for two weight classes of aeroplanes having identical power plants are presented. The comparison of the single-engined level flight performance, feathered, vs. the windmilling condition shows the definite advantage of the former. The effect on the single-engined rate of climb of feathered and windmilling propellers in high pitch is charted for the heavier of the two classes considered.

Engine oil temperature is found to be the greatest factor affecting the friction horsepower and subsequent drag effects of the windmilling engine-propeller combination. Charts showing variations in friction horsepower with oil temperature are presented.

Full-feathering propellers are recommended for all multi-engined aeroplanes.

A Study of Design Conditions for Tricycle Landing Gear. (C. J. Wenzinger and R. T. Jones, J. Aeron. Sci., Vol. 5, No. 1, May, 1938, pp. 260-5.) (57/18 U.S.A.)

Some design conditions that will permit the inherent safety features of the tricycle landing gear to be more or less fully utilised are set forth. The paper covers the definitions of the landing conditions, reasons for the choice of certain values, and includes incidental references to the application of the conditions in determining the structural loads.

The proposed conditions are based on vertical velocities, rates of drift, pitching motion, etc., that have been observed in landing tests or that seem likely from particular experiences with conventional landing gears. In addition, the probable use and method of operation of different classes of aeroplane have been considered. The ultimate criteria, however, must await further experience with the tricycle landing gear and full-scale tests of the loads developed under operating conditions.

Some Problems in the Design of High Speed Aircraft. (L. H. Leonard, J. Aeron. Sci., Vol. 5, No. 7, May, 1938, pp. 273-7.) (57/19 U.S.A.)

An analysis of important technical problems in the design of high-speed aircraft is presented. The results are illustrated by graphs that show the comparative effectiveness of different methods of increasing flying speed. High wing loading is revealed to be the greatest need for higher speeds at sea level. The optimum wing loading for maximum flying speed is shown to be that required to fly at the maximum L/D of the wing and tail surfaces. The increase in the optimum wing loading with flying speed at sea level and its variation with altitude are graphically illustrated. At 400 m.p.h. the optimum wing loading is shown to be of the order of 300lb. per sq. ft. at sea level but it is only 25lb. per sq. ft. at 60,000 ft. altitude. Design alterations permitting higher wing loadings than are now in use are recommended.

Performance and Control of Rotary Wing Aircraft. (E. Burke Wilford, J. Aeron. Sci., Vol. 5, No. 7, May, 1938, pp. 278-280.) (57/20 U.S.A.)

In order to increase the top speed of rotary wing aircraft, the author recommends using a combination of fixed and rotary wings. The rotor blade mechanism must be under positive control and the fixed wing area is adjusted so that it will support the weight of the machine at cruising speed (max. L/D of fixed wing). At high speeds the rotor is unloaded and will then slow down, rotation being kept up by difference of drag and not by autoration. Under these conditions the L/D of the combination will be high and the speed and climb will be comparable to that of orthodox aircraft. The slow landing speed and steepness of descent and ascent will, however, be far superior to that of fixed wing machines.

The author presents his conclusion in tabular form, the gross weight of the aircraft being 3,400lb. and the h.p. 420 in each case.

Whilst the relative top speed of fixed wing and rotary wing machines are 206 and 149 m.p.h. respectively, the combination of fixed and rotary wing may reach 176 m.p.h. If the rotor is stopped in the high speed condition, 200 m.p.h. may be reached.

Ground Effect with Special Reference to Pitching Moments. (W. R. Sears, J. Aeron. Sci., Vol. 5, No. 7, May, 1938, pp. 281-5.) (57/21 U.S.A.)

(1) The principal effect of the ground on the pitching moments of an aeroplane (as determined by wind tunnel tests using a fixed ground plate) is an increase in the slope $(-dC_{Mt}/dC_L)$ (where C_{Mt} = coefficient of pitching moment due to tail). This is accompanied by very little change of moment at zero lift, and either no change or a slight increase in stalling moment available from elevator deflection. The net result is a considerable limitation of the allowable forward travel of the centre of gravity if trim is to be attained in the three-point landing attitude near the ground. The experimental results are not in close quantitative agreement with the present approximate theory.

(2) The " effective aspect ratio " of the aeroplane near the ground plate is greater than that away from the ground, as indicated by curves of lift, drag, and angle of attack.

(3) The maximum lift coefficient of the complete aeroplane model may be either increased or decreased by the presence of the ground plate.

Stress Model of a Complete Airship Structure. (L. H. Donnell, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 67-77.) (57/22 U.S.A.)

The authors discuss considerations in designing stress models in general, and the construction, rigging, and testing of an airship model in particular. A new type of girder representation is described, having the unusual advantages of varying the axial, bending, and torsional characteristics independently, and of incorporating convenient and sensitive means for measuring the corresponding stresses. Tests on a separate braced-ring model are compared with theory, and appear to be in good agreement. Similar tests on a duplicate ring in the complete model show the influence of the surrounding structure.

A Discussion of Certain Problems Connected with the Design of Hulls of Flying Boats and the Use of General Test Data. (W. S. Diehl, N.A.C.A. Report No. 625, 1938.) (57/23 U.S.A.)

A survey of the problems encountered in applying general test data to the design of flying-boat hulls is presented. It is shown how basic design features may be readily determined from special plots of test data. A study of the effect of the size of a flying boat on the probable limits to be covered by the general test data is included and recommendations for special tests and new methods of presenting test data for direct use in design are given.

The following main conclusions were reached:—

(1) The range of loads and speeds necessary to supply data for a normal size flying boat appear to be ample to cover future increases in size.

(2) There appears to be need for investigation of the following:—

(*a*) fore and aft location of step and best location of c.g. relative to step.

(*b*) best initial trim.

(*c*) effect of thrust moment and elevator moment on trim angles. This will probably require measurement of pitching moments in the full scale wind tunnel.

A Flight Investigation of the Reduction of Aileron Operating Force by Means of Fixed Tabs and Differential Linkage with Notes on Linkage Design. (H. A. Soule and J. A. Hootman, N.A.C.A. Tech. Note No. 653, June, 1938.) (57/24 U.S.A.)

Flight tests were made to demonstrate the practicability of employing fixed tabs in conjunction with a suitably designed differential linkage to reduce the force required to operate ailerons. The tests showed the system to be practicable with tabs of the inset type. Experience gained in the investigation has indicated that the use of the system is limited to maximum deflections of one aileron relative to the other of less than 30° and that the differential linkage should always be designed on the basis of the highest probable floating angle.

The Problem of Ring Sticking in Aviation Engines. (O. C. Bridgeman, J.S.A.E., Vol. 41, No. 6, Dec., 1937, pp. 545-7.) (57/25 U.S.A.)

The author considers the mechanism of ring-sticking to be essentially a two-stage process. The first stage is due to the restriction of movement placed on the ring by thickened oil and unburnt fuel residues. This restriction retains a portion of the oil and fuel residue in the ring grooves long enough to allow the second stage to take place. The high temperature now gums the oil to the condition in which no movement of the ring is possible. Control of temperature, keeping it below the critical temperature for the type of aviation oil available, is perhaps the most certain method of avoiding ring-sticking, and every effort should be made to increase the rate at which heat is removed from the piston.

One of the most serious handicaps to the improvement of oils is the lack of a significant method for determining oil stability under conditions operating in the engine when ring-sticking occurs. Oils used in aviation engines appear to be at least one grade and possibly two grades too heavy, and investigations with lighter oils might go far towards solving some lubrication problems.

Faulty rings are often the cause of ring-sticking and specifications on circularity and distribution of tension should be adopted as a first step towards reduction in ring-sticking.

Acquisition of accurate measurements on ring temperatures, and research on design of piston rings and grooves, together with the development of suitable oil test methods are urgently needed.

Investigation on Wear of Piston Rings. (E. Seibel and Kehl, Year Book of German Aeronautical Research, 1937, Vol. 2, pp. 212-3.) (57/26 Germany.)

Five samples of piston ring material were tested for wear in a special machine, the samples being stationary and pressed against a rotating ring made of cast iron or steel.

The torque required at a steady speed is recorded continuously, the wear being measured by weighing the samples at stated intervals.

The experiments were divided into three groups:—

1. Running in (limited oil supply).
2. Wear after running in (normal oil supply).
3. Relative tendency to seizure.

1. For these experiments the contact pressure and rubbing surface temperature were maintained constant and the oil supply adjusted to one drop every five seconds.
2. In order to cut down the time for measurable wear a small percentage (0.1 per cent.) of emery powder was added to the oil.
3. The relative tendency to seizure was measured by gradually increasing the contact pressure of the polished samples till the torque curve showed a discontinuity after two minutes' operation.

The results of the experiments show that the relative order of merit of the samples changed under conditions 1, 2 and 3, and more correlation with engine tests is required before a satisfactory laboratory method for testing wear can be developed.

Aero Engine Working Hour Counter "Peravia." (Inter. Avia., No. 547, 28/5/38, p. 7.) (57/27 Switzerland.)

This very ingenious instrument keeps a record of the load imposed on the engine in service by integrating the total number of engine revolutions in terms of the boost pressure. If, for example, the engine is operating under steady cruising conditions, the lowest disc of the counter mechanism makes one revolution per hour. If the boost pressure is less or greater than this, the gear ratio is altered accordingly, the change being linear in the first and according to a square law in the second instance.

The change in gear ratio is brought about by interposing a variable cam contour which limits the return stroke of a ratchet engaged with the counter. This variable cam contour is under the control of a pressure box system, the inside of which communicates with the atmosphere whilst the outside is subjected to the engine boost pressure.

The weight of the instrument is of the order of $1\frac{1}{2}$lb. and it is stated that after extensive trials it will shortly be introduced on a large scale into the Air Force of a Great Power.

New Type Turbo-Compressors with Intermediate Cooling. (B. Lendorff, Metropolitan Vickers Tech. News Bulletin, No. 615, 17/6/38, p. 11. Esch. Wyss. N., January-March, 1938, pp. 3-8.) (57/28 Germany.)

Several new designs of turbo-compressor which are here described, are based upon investigations carried out by the Escher Wyss research department. One notable improvement among others relates to the design of the diffusers and return channels in multi-stage radial turbo-compressors, which improvements have been incorporated in machines with inter-coolers. Illustrated with two photographs and five diagrams.

The Technique of Anti-Freeze Testing. (K. H. Hoover and F. E. Dolian, Ind. and Eng. Chem. (Analytical Edn.), Vol. 10, No. 6, 15/6/38, pp. 293-7.) (57/29 U.S.A.)

The suitability of an anti-freeze solution for use in a water-cooled internal-combustion engine is determined by the inherent properties, *i.e.*, physical constants of its principal component and by the properties imparted to it by the addition of certain modifying agents. The technique of testing the corrosive action on metals, storage properties, attack of rubber, and foaming tendency is discussed, and various apparatus are described. Particular emphasis is placed on methods of testing corrosive action which closely simulate actual conditions as found in automobile cooling systems. Field tests and their limitations are discussed.

A Laboratory Test Method for the Tendency of Lubricating Oils to Produce Ring Sticking. (M. Richter, Luftwissen, Vol. 5, No. 6, June, 1938, pp. 213-218.) (57/30 Germany.)

After a review of previous work on this subject, the author describes the D.V.L. laboratory method.

10 gm. of the oil are placed in a flat bottomed glass dish (88 mm. diameter and 18 mm. high). The glass dish is heated by immersion in a liquid metal bath (lead-tin), the temperature of the oil being kept at 275°C. for four hours. The bath is placed in a fume cupboard with forced ventilation and free access of fresh air to the dish. After the four hours, the loss of oil by evaporation as well as the asphalt content of the residue are determined. The quality of the oil is expressed by multiplying these two factors together and dividing by a thousand. The smaller this final product, the better the oil from the point of view of ring sticking.

The conclusions were tested by experiments in a single cylinder air-cooled engine of 384 cc. stroke volume and compression ratio 4.5. This engine has a cast iron piston and was operated at a spark plug boss temperature of 380°C., the ring sticking being marked by drop in power.

It is stated that a satisfactory agreement between the two methods of rating was obtained provided oils of a similar nature were compared (fatty oils naphthenic oils and mixed oils). With synthetic oils the results, as given, appear to be rather erratic.

Fuel Consumption of a Carburettor Engine at Various Speeds and Torques. (O. W. Schey and J. D. Clark, N.A.C.A. Tech. Note No. 654, June, 1938.) (57/31 U.S.A.)

The results of tests on two single-cylinder engines (Wright 1820-G and P. & W. 1340-H) show that:—

1. In order to obtain minimum specific brake fuel consumption, an engine should be operated at high torque and at speeds from 60 to 70 per cent. of the rated speed. Operating at 45 per cent. of maximum torque increased the fuel consumption 20 per cent. over the fuel consumed at maximum torque when the engine was operating at 70 per cent. of rated speed.
2. The indicated mean effective pressure and the engine speed had only a small effect on the minimum indicated fuel consumption within the practical range of operation.
3. An engine having a compression ratio of 5.6 can burn as lean a mixture as an engine having a compression ratio of 7.4.
4. Practically no improvement in fuel consumption was obtained by operating with mixtures leaner than an air-fuel ratio of 15.5.
5. A method for reducing the amount of testing necessary to obtain minimum brake fuel-consumption curves is proposed.

Report on Liquid Methane. (M. Ruhemann, Summary available in R.T.P.) (57/32 Great Britain.)

The report is divided into three sections:—

I. Possible sources of supply of gaseous methane.
II. Production of liquid methane.
III. Storage and transport of liquid methane.

On the assumption that liquid methane forms a desirable aero engine fuel, the author concludes that sewage gas would form a suitable source of supply. Large scale liquefaction costs (including purification) would be less than ¾d. per gallon and by suitable extension of existing sewage works a proportion of our liquid fuel requirements could be met.

This source of supply for methane is to be preferred to the utilisation of coal and coke oven gases, since the latter cannot be robbed of their methane content without upsetting both the energy and economic balance of the process.

The loss in weight of liquid methane by evaporation during 24 hours is of the order of 1-2 per cent. in vacuum vessels and 3-8 per cent. in lagged tanks.

The author is of the opinion that a specific tank weight acceptable for aircraft use should be realised after some development work. In this connection the low density of the liquid methane (0.42) should be of some assistance.

Permissible Load in High Speed Lubricated Bearings. (H. Thoma, Forschung, Vol. 9, No. 3, May-June, 1938, pp. 149-58.) (57/33 Germany.)

The bearing temperatures permissible in service are restricted by the low viscosity of the oil, and by the gas discharge and evaporation phenomena within the oil film. In high speed bearings, the greater part of the heat produced by friction must be dissipated by the oil stream which passes through the oil film. If, in conformity with experience, a temperature rise of 50°C. is permitted, a resultant maximum pressure of 50 kg./cm.^{2} is found, which is independent of the surface speed, the dimension of the bearing, and the oil viscosity. An expression for calculating the bearing play required under various conditions concludes the article.

Symposium on Lubricants. (American Society for Testing Materials, Philadelphia, Pa.) (57/34 U.S.A.)

This booklet of 90 pages covers the following aspects:—

(1) Engine deposits.
(2) Automotive bearings.
(3) Addition agents for motor oils.
(4) How to select a motor oil from the standpoint of the consumer.

(1) The various deposits occurring in the combustion chamber, crankcase, or on the valves and pistons, are reviewed. The advent of leaded fuels has still further complicated matters. No satisfactory laboratory test (with the possible exception of crankcase sludge) is as yet available.

(2) Various forms of bearing testing machines are described and considerable attention is paid to the nature of the bearing material (mechanical strength, fatigue limits, anti-friction and non-scoring properties, corrosion, etc.).

(3) The addition agents are classified under the heads: oiliness, pour inhibitors, viscosity index improvers, anti-oxidants and carbon removers. The difficulty is again the absence of a comprehensive laboratory test. In the long run it is the behaviour in the engine which counts, and it may turn out that an addition agent which shows up well under certain laboratory conditions will fail under the more complicated practical conditions.

(4) " The best way to select a motor oil from the standpoint of the consumer is to follow the advice of the oil and engine manufacturer." In other words only practical experience counts.

Viscosity Measurements. (M. R. Cannon and M. R. Fenske, Ind. and Eng. Chem. (Analytical Edn.), Vol. 10, No. 6, 15/6/38, pp. 297-301.) (57/35 U.S.A.)

Viscosity and viscosity temperature coefficients are valuable identifying properties of pure compounds and petroleum fractions. This paper discusses the operating characteristics of simple modified Ostwald viscometers that are suitable for covering a wide range of viscosity with accuracy. The important sources of error in capillary viscometers are analysed briefly, and equations for computing

the necessary corrections are given. Comparisons are made with other types of capillary viscometers which show that the modified Ostwald is equal in accuracy to any now available.

A Height Computer for Use in Aerological Work. (E. G. Bilham, M.O. Prof. Notes, No. 80, 1938.) (57/36 Great Britain.)

As is well known the difference in altitude h corresponding to an observed pressure difference in the atmosphere is given by the equation:—

$$h = C \cdot T_m \log_{10} (p_o/p)$$

C is a constant and p_o and p are the relative pressures and T_m the harmonic mean temperatures of the air between the two levels. If this temperature were constant and known, a (log) pressure scale could be directly converted into an altitude scale. A difference in the constant mean temperature can be allowed for by rotating the altitude scale through an angle α such that $\cos \alpha = T_{m1}/T_{m2}$ and projecting from the pressure scale vertically upwards on to the inclined altitude scale.

If a series of simultaneous pressure and temperature measurements are thus available during an ascent, T_m can be calculated in steps and the altitude scale adjusted accordingly. The actual elevation corresponding to the pressures can then be read off as explained.

An apparatus designed on these lines is described and its accuracy estimated.

Diaphragm Motor Valves. (E. H. Hammond, Metropolitan Vickers Technical News Bulletin, No. 613, 3/6/38, p. 14. Power, May, 1938, pp. 68-70.) (57/37 Great Britain.)

Types of diaphragm motor valves for control of liquids are described and discussed. They are operated by fluid pressure applied to a flexible diaphragm connected to the valve stem which is spring loaded. Design modifications to suit particular applications are indicated. Illustrated with six photographs and three diagrams.

Seeing the Unseen. (R. Merwin Horn, Mechanical Engineering, U.S.A., Vol. 60, No. 3, March, 1938, pp. 199-201.) (57/38 U.S.A.)

Some details of the high speed camera of the Massachusetts Institute of Technology are given.

The camera uses standard 35 mm. film, the illumination being by means of an electric spark of very short duration (10^{-5} sec.). The number of sparks per second is governed by a commutator which is synchronised with the film drive so that exposures only take place when the film has moved a sufficient distance to prevent overlapping. As many as 6,000 exposures can be taken per second, corresponding to a film speed of 375 feet per second. The film speed being accurately known, the photographs can be measured up to yield information as regards irregularities of motion. As an example, a film showing a club hitting a golf ball is given. The club velocities before and after impact are 166 to 122 feet per second respectively, and the spin of the ball corresponds to 5,200 r.p.m.

Status of Instrument Landing Systems. (W. E. Jackson, Proc. Inst. Rad. Eng., Vol. 26, No. 6, June, 1938, pp. 681-699.) (57/39 U.S.A.)

Various types of wireless landing systems undergoing test or development in the U.S.A. are described, special attention being paid to the Lorenz system demonstrated at the Indianopolis Airport.

As a result of experience, the relative advantages and shortcomings of various systems are now understood and the major U.S. airlines as well as the U.S. Government have reached an agreement as to desirable features of a practical

instrument landing system. Such essential elements as runway localisers, glide path and markers are analysed and it is hoped that, by combining the best features of all the systems, a standard form of equipment will be available shortly. When this condition is reached, it is recommended that the Bureau of Air Commerce purchase, instal and operate these instruments at various airports throughout the U.S.A. on an experimental basis.

Distance Recorder for Firedamp. (Metropolitan Vickers Tech. News Bulletin, No. 609, 6/5/38, p. 7. S. African Mining and Eng. J., 26/3/38, pp. 117-8.) (57/40 S. Africa.)

This instrument is capable of continuously recording the percentage of firedamp in the neighbouring atmosphere. The principle adopted is the straightforward mechanisation of a common method of gas analysis as carried out manually in the Haldane apparatus. Air is pumped into a chamber where an incandescent platinum wire combusts any methane present. The reduction in pressure is recorded. The instrument is built with at least two chambers for check analysis. A distance recorder can be connected and consists of a resistance circuit influenced by an aneroid pointer. Voltage impulses occur each time the striker is depressed to print a reading on the thread recorder.

One illustration and three diagrams (including remote recorder circuit) are included.

Magneto-Elastic Recording of Torsional Vibrations. (S. Wintergerst, Forschung, Vol. 9, No. 3, May-June, 1938, pp. 162-4.) (57/41 Germany.)

The author has investigated in a previous paper the magnetic recording of longitudinal oscillations (Forschung, Vol. 8, 1937, p. 238). This case is relatively simple, since the state of stress is mono-axial. The problem of torsion, however, implies a bi-axial stressing and matters are further complicated, if, as is usual, the manufacture of the shaft has led to the formation of various strains which remain in the material.

The author, however, shows that, provided the amplitude of the torsional oscillation is small, the change in magnetic induction of the material is proportional to the change in stress resulting from the torsion. Either a circular or longitudinal magnetic induction can be applied externally to the shaft, but in many cases the remanent magnetism is sufficient for recording purposes. The records are obtained by measuring by means of an oscillograph the E.M.F. induced in a coil which either surrounds the shaft or is placed in close proximity to its surface. In the latter case the coil has a U shaped soft iron core, the orientation of which determines whether changes in longitudical or circular induction are measured. The induced E.M.F. is proportional to the change in stress and require integration to give the actual stress. Magnetic elastic recording can be used for very high frequencies and the method is both accurate and simple provided the change in stress does not exceed 2 kg./mm.

New Nozzle Shapes for Low and Medium Reynolds Numbers. (W. Koennecke, Forschung, Vol. 9, No. 3, May-June, 1938, pp. 109-25.) (57/42 Germany.)

The nozzles for low Reynolds numbers described in the D.I.N. " Rules for Flow Measurement with Standardised Nozzles and Orifices " do not show the constancy required for metering purposes if employed in the range below Re about 10^5.

The field of application of these nozzles is, moreover, restricted by the fact that they may be used only with a definite orifice ratio. The aim of the present paper is to describe new nozzles shapes possessing constant flow coefficients over the widest possible range of Reynolds numbers and orifice ratios.

Investigation on Outflow Measurements with Sharp-Edged Orifices. (W. Schultes, K. Jaroschek and H. Werkmeister, Forschung, Vol. 9, No. 3, May-June, 1938, pp. 126-38.) (57/43 Germany.)

While standards have been established for nozzles and orifices for measuring the flow through closed pipe lines, no standards are yet available for the important class of outflow measurements in which the discharged volume is determined from the head prevailing in the container. The head and the effect of the discharge nozzles or orifices are influenced by the flow conditions within the container, which so far have not been sufficiently elucidated. The present investigations cover the most important of the prevailing phenomena, with a view to formulating a standardised method of outflow measurement.

The Wear of Electrical Contact Points. (W. Betteridge and J. A. Laird, J. Inst. Elec. Eng., Vol. 82, No. 498, June, 1938, pp. 625-32.) (57/44 Great Britain.)

An examination has been made of the phenomena occurring during the operation of electrical contacts, with particular reference to the destructive effects produced on the contact points. Four main stages in the break of a current have been observed, of which the resistance rise, the arc, and the spark, are well known; intermediate between the resistance rise and the arc is a stage in which the gap between the contact points is bridged by a drop of molten metal; this latter is of great practical importance since it is of almost universal occurrence, causes well-marked transference of contact material, and, as the potential difference between the contact points is then only about 2 volts, it cannot be suppressed by modifications of the interrupted circuit. The voltage-current-length characteristics of the molten bridge between electrodes of platinum-iridium (25 per cent. Ir.) have been determined and are found to be of a similar form to those for an ordinary arc, *i.e.*, voltage inversely proportional to current and directly proportional to length. The reason for such characteristics is not known.

The conditions of voltage and current necessary for the formation of the different stages are described, and the effects produced by typical simple circuits are dealt with.

Suggestions are made which should help to reduce the wear of contact points to a minimum.

Direct Reading Air Velocity Meter. (Metropolitan Vickers Gazette, June, 1938, pp. 284-8. Metropolitan Vickers Tech. News Bulletin, No. 616, 24/6/38, p. 13.) (57/45 Great Britain.)

This portable instrument, known as the Metrovick "Alnor" Velometer employs the Boyle system and indicates air velocities in feet per minute directly on a scale. It is supplied in either the tube or the orifice type, both of which are fully described. Its sphere of usefulness embraces air conditioning and ventilation systems, ventilating systems for machinery, aircraft manufacture, metal foundries and mines. Illustrated with five photographs and one diagram.

The Protection of Metals by Aluminium. (Metropolitan Vickers Technical News Bulletin, No. 614, 10/6/38, p. 5. Light Metals, June, 1938, p. 188.) (57/46 Great Britain.)

This is a brief review of composite materials in which pure aluminium or a special alloy is used to protect a ferrous metal or light alloy against corrosion. It deals with the calorising process, by which the aluminium is to some extent alloyed with the surface of the metal being protected, and the use of alloys for plating.

Electrically Conductive Rubber. (Metropolitan Vickers Technical News Bulletin, No. 614, 10/6/38, p. 6. El. Rev., 3/6/38, p. 800.) (57/47 Great Britain.)

This article deals with a semi-conducting rubber material developed by the Dunlop Rubber Co. It is stated that rubber having good mechanical properties is available with a specific resistance of 1 ohm per cm. cube and upwards. Possible applications are indicated and are mainly in connection with preventing the accumulation of electrostatic charges.

Indium Treated Bearing Metals. (C. F. Smart, Metropolitan Vickers Tech. News Bulletin, No. 610, 13/5/38, p. 2. Met. Vickers, April, 1938, Tech. Publ. 900.) (57/48 Great Britain.)

It is pointed out that cadmium alloy bearings, which are better able to withstand the higher stresses and temperatures of modern automobile engines, are subject to corrosion from acid lubricating oils. It has been found, however, that the addition of fractional percentages of indium to these alloys prevents corrosion, and tests on indium treated bearings are described which demonstrate this fact.

Illustrated with five photographs.

Electron Diffraction Applied to Corrosion Study. (I. R. Landau, Metropolitan Vickers Tech. News Bulletin, No. 609, 6/5/38, p. 7. Metals and Alloys, April, 1938, p. 7.) (57/49 Great Britain.)

Electron diffraction patterns for the following types of coating are given and discussed: rust; non-ferrous oxides and tarnishes; non-integral protective coatings such as platings and painted finishes. In conclusion the limitations of electron diffraction, and its scope in engineering are indicated. Illustrated with five photographs.

Metallography of Welding. (O. H. Henry, Metropolitan Vickers Tech. News Bulletin, No. 609, 6/5/38, p. 14. Welding Journal, April, 1938, pp.8-14.) (57/50 Great Britain.)

The author deals first with the mechanism of crystallisation and crystal structures produced by different heat treatments of steels. He then applies this knowledge to explain and describe the varying crystal structure throughout the cross-section of an arc weld, and in the adjacent metal.

Illustrated with 11 microphotographs and five diagrams.

The Use of Phenol Formaldehyde in Photoelastic Investigations. (A. Kuske, Forschung, Vol. 9, No. 3, May-June, 1938, pp. 139-49.) (57/51 Germany.)

The mechanical and optical properties of the synthetic resins used in two dimensional photoelastic experiments and in the so-called "solidification" method are not known very accurately. A clearer insight is afforded into the optical and mechanical behaviour of the synthetic resins by a new diphase theory. The knowledge gained with the aid of this theory, and from the tests described, is applied by the author to practical problems of two and three dimensional photoelasticity.

Suitability of Various Plastics for Use in Aeroplane Dopes. (G. M. Kline and C. G. Malmberg, Bur. Stan. J. Res., Vol. 20, No. 5, May, 1938, pp. 651-71.) (57/52 U.S.A.)

A number of different cellulose derivatives of potential interest as film-forming constituents for aeroplane dopes have recently become available commercially. An investigation has been undertaken at the National Bureau of Standards to determine the fundamental factors involved in the formulation of dopes containing these new derivatives to obtain optimum tautness and durability. Data are presented in this paper relative to the effect of varying the acyl or ethoxyl content

and the viscosity of cellulose esters and ethers on the tautness of fabrics doped with them. It is concluded that the solvents and diluents govern, to a large extent, the tautening properties of the dope and the durability of the film deposited on the fabric.

Rapid Test for Anodic Coatings. (Light Metals, Vol. 1, No. 4, May, 1938, p. 122.) (57/53 Germany.)

A rapid electrolytic test for the porosity of anodised coatings on aluminium has been devised in Germany. The specimen is immersed in a 3 per cent. solution of barium chloride containing phenolphthalein and connected to a four-volt accumulator, the positive pole of which is connected to a copper plate dipping in the same solution. The degree of porosity of the coating can be estimated from the current flowing through the cell, or from the number of pink spots appearing on the surface of the specimen.

A modification of the method in which the solution is applied by filter paper laid on the surface of the metal is also suggested.

A New Relationship for Use in the Design of Machine Columns. (W. H. Clapp, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 52-4.) (57/54 U.S.A.)

The author discusses the requirements of an ideal formula for determining the stresses in machine columns, and points out the fact that although the secant formula meets several of these requirements, the relationships are so involved that is has always been necessary to use one of several empirical equations, because of the uncertainty regarding the probable eccentricity of the load. The author describes a relationship which makes the secant formula usable, and presents a universal chart adapted to the solution of problems of steel columns having any type of cross section when subjected to axial loading.

Correlation of Creep and Relaxation of Copper. (C. C. Davenport, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 55-60.) (57/55 U.S.A.)

Creep tests, as well as relaxation tests, have been carried out in torsion on copper tubes which permit a verification of the various theories proposed for a deduction of the relaxation characteristics from creep tests alone. It was found that the actually observed relaxation time lies between the two values calculated for this quantity on the basis of the strain-hardening and the time-hardening theories.

An Improved Method for Calculating Free Vibrations having Several Degrees of Freedom. (W. M. Dudley, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 61-66.) (57/56 U.S.A.)

In 1934, Duncan and Collar (Phil. Mag., Vol. 17, pp. 865-909) published a method for calculating the various modes and frequencies of vibration of a system having several degrees of freedom. Their method, which is based on matrices, greatly shortens the time spent in obtaining numerical solutions in many important problems, notably those with immovable foundations. In this paper is presented a new theorem which (*a*) makes possible a further reduction of nearly one half in the time required, so that solutions up to 20 deg. or more of freedom are now practical and (*b*) makes it then possible to determine the motion of the system after any initial disturbance in a few minutes, instead of several hours, as required by older methods. It is useful in the latter respect, whether the modes have been determined by matrix methods or not.

Although the paper gives simpler proofs than any previously published, knowledge of the matrix theory is not required in using the method. Problems are analysed by a tabular process, in which an ordinary computing machine helps greatly. Comments based on computing experience are given.

Circular Beams Loaded Normal to the Plane of Curvature. (M. B. Hogan, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 81-5.) (57/57 U.S.A.)

This paper presents expressions for the deflection, angle of slope, and angle of twist of the free end of a circular cantilever beam with a concentrated load acting at any point along the centre line of the beam and perpendicular to its plane of curvature. Similar results are also given for three different cases of distributed loading. The values of the reaction and the angles of slope and twist at the simple support are given for a circular beam built-in at one end, simply supported at the other and loaded as in the first of the above cases. Finally, equations are given for the three internal reactions: Bending moment, twisting moment, and shear existing at the plane of symmetry of a circular beam built in at both ends with an arbitrarily placed concentrated load acting perpendicular to the plane of the arc and at its centre line.

Tables of Stiffness and Carry-over Factor for Structural Members under Axial Load. (E. E. Lundquist and W. D. Kroll, N.A.C.A. Tech. Note No. 652, June, 1938.) (57/58 U.S.A.)

Tables of stiffness and carry-over factor are presented for members in which the cross section and axial load do not vary along the length of the member. These tables are of use in solving problems in the stability of structural members under axial load as well as in applications of the cross method of moment distribution when the effects of axial load in the members are considered. The interval between successive values of the argument is small enough to make interpolation unnecessary in engineering calculations.

New Researches on the Al-Si Alloy (Silumin Gamma) with Special Reference to Aero Engine Requirements. (P. Koetzschke, Luftwissen, Vol. 5, No. 6, June, 1938, pp. 205-211.) (57/59 Germany.)

The eutectic Al-Si alloy (containing app. 12 per cent. Si) is well known for its excellent casting properties and has received extensive application in Germany for engine crankcase and cylinder heads of water-cooled engines. For air-cooled engine heads, however, the material proved unsuitable, since at elevated temperatures it is considerably weaker than other aluminium alloys containing copper or nickel. The author describes experiments carried out with the Silicon alloy with the object of overcoming this drawback by replacing a portion of the Silicon content with copper, cobalt or manganese.

The following results were obtained:—

1. The addition of copper, cobalt or manganese does not improve the high temperature qualities of the Silicon alloy sufficiently to replace the standard Al-Cu or Al-Ni alloys for air-cooled cylinder heads.
2. For water-cooled engines, however, the addition of Co or Manganese has proved beneficial in raising the fatigue limits slightly without impairing the good casting qualities of the original.

Absorption and Dispersion of Sound in Liquids. (H. O. Kneser, Ann. d. Physik, Vol. 22, No. 3, June, 1938, pp. 277-289.) (57/60 Germany.)

Based on general principles, the author develops formulæ for the absorption and dispersion accompanying the propagation of sound in liquids. The formulæ are of similar types to those holding for the case of gases, the effect of frequency on absorption and speed of propagation being expressed by suitable constants.

The author has collected experimental data on 12 liquids for comparison with his theory and the results are in general agreement. The reason for certain discrepancies are investigated and the effects of temperatures and concentration of mixtures are elucidated.

Heat Dissipation Through an Annular Disk or Fin of Uniform Thickness. (W. M. Murray, J. App. Mech., Vol. 5, No. 2, June, 1938, pp. 78-80.) (57/61 U.S.A.)

The subject matter considered in this paper deals with the mathematical investigation of heat flow in an annular disk of uniform thickness. Originally, the investigation was carried on in connection with the design of fins for increasing the heat transfer in various kinds of heat exchangers and engines. The results of the study, however, can easily be applied to a number of other problems, since by altering the boundary conditions slightly one may use the same basic equations for calculating the temperature distribution and heat transmission in grinding wheels and disk clutches.

The study of the problem in connection with fin design has brought forth other solutions for special cases of the general proposition considered here. The particular results obtained by previous investigators can be readily found from the general equations given in this paper. In order to assist in the numerical solution of the somewhat complicated equations a chart for evaluating the mathematical expressions has been included.

Electricity on Rain—A Discussion of Records Obtained at Kew Observatory 1935-6. (F. J. Scrase, M.O. Geophysical Memoir No. 75, 1938.) (57/62 Great Britain.)

The data on which this investigation is based were obtained from continuous photographic records of the charge brought down by unit amounts of rain at Kew Observatory during the years 1935-6; a detailed description of the apparatus is given.

The results of an analysis of the records showed that about three quarters of the rain was positively charged, but owing to the fact that the charge per unit volume was, on the average, much greater in the case of negatively charged rain, the total quantities of positive and negative electricity brought down were not very different. On the whole, positive charge was slightly in excess. Showers were responsible for most of the high negative charges, whilst continuous rain and thunderstorms were generally associated with excess of positive charge.

The potential gradient at the ground was much more often negative than positive during positively charged rain, but in negatively charged rain there was no marked tendency for the gradient to be of one sign rather than the other.

The results appear to be consistent with the view that the electrification of shower clouds is brought about by the impact of ice crystals. It is suggested that the same process is responsible for the initial separation of electricity in a thundercloud, but that as a result of the more violent ascent of air local regions of positive charge are generated near the base of the cloud by the breaking-drop process.

It is not clear how the electrification of continuous rain is produced, but it is believed that the prevalence of negative potential gradient in this type of rain is the result rather than the cause of the transfer of positive charge from the clouds to the ground by the rain.

The Propagation of Radio Waves Over a Finitely Conducting Spherical Earth. (P. Van der Pol and H. Bremmer, Phil. Mag., No. 171, June, 1938, pp. 817-34.) (57/63 Great Britain.)

An extension is given to the applications in the radio case of a general theory treated in two former papers on the problem of diffraction of electro-magnetic waves round an absorbing sphere. Asymptotic series have been derived from which the numerical constants occurring in the final formula may be calculated for the field strength of a sender emitting waves over a homogeneous sphere with

arbitrary electrical conductivity and dielectric constant; the sender and receiver are hereby supposed to be situated on the earth. The general results are compared with those of Eckersley and Wwedensky, treating the same problem. Finally, curves are given showing the field strength as a function of the distance for propagation over sea-water and over average soil.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

SIR,—From the viewpoint of the aeroplane designer, I was particularly interested in Mr. Relf's recommendation in his lecture on " Recent Research on Aerodynamics " for the improvement of lateral stability near the stall by means of appropriate shaping of the wing tips, with tapered wings.

A similar arrangement has been used for a small low wing monoplane I designed in 1936 and tested first in January, 1937. This light single-seater, the Dart Kitten, has a tapered cantilever wing which combines perfect flying qualities in stalled and unstalled conditions with good performance, as proved by extended flight tests.

The following figures were derived from performance tests and competitions :—

Climb near the ground, $\eta^2 C_L^3/C_D^2 = 47{\cdot}5$.
Maximum speed at 1,000ft. height, $\eta/C_D = 21.6$.
Stalling speed at 1,000ft. height, $C_{L\max} = 1{\cdot}7$.

The Kitten has been tried by about 200 pilots of vastly different experience (between 6 and 4,000 hours flying) without the slightest incident, and every pilot found it exceptionally easy to handle.

The aerodynamic design of the Kitten wing was based on the intention to obtain with simple means, a non-vicious stall with lateral control at the stall, and to safeguard against tailplane buffeting with which I have previously had some acquaintance in low wing types.

In order to exclude buffeting, the centre section of the wing, covering the span of the tailplane, was designed with a wing section having a very gradual stall in the range of all practically occurring Reynolds numbers. I chose the N.A.C.A. 6318 aerofoil. The sections of the outboard wing were derived from the N.A.C.A. 230 series which show a front stall. For the wing tip (at 96.6 per cent. of the semi-span) the N.A.C.A. 4409 section was chosen.

An aerodynamical wash-out delays the stalling of the wing tips and safeguards the aileron control near the stall, the range of incidence between no-lift and maximum lift being greatest at the wing tips. Dr. Lachmann has referred to the combination of twist with change of camber in his paper dealing with the features of tapered wings.

The wing of the Dart Kitten has a single spar with shear boxes, a ply covered wing nose taking the torsional loads. The distinct gull-wing shape near the tips is the result of the aerodynamical arrangement mentioned.

The Dart Kitten proved to have a non-vicious and a very gradual occurring stall. When stalled the plane was merely sinking on an even keel with complete aileron control. Solely with the help of the very powerful rudder a spin could be effected, the check of which was easy and rapid. In a completely stalled condition with the engine throttled back, only a negligible amount of tailplane buffeting could be discovered (no wing root fairing). It was harmless and therefore perhaps even useful because it was the only sign of warning that the plane was flying stalled (besides the loss in height). In a power stall buffeting did not set in.

According to this experience I should say that the use of cambered wing tip aerofoils with rearward position of the maximum camber has proved successful for the prevention of wing dropping. But at the same time I should hesitate to recommend this arrangement for very fast aeroplanes; under certain conditions wing flutter might be expected.

Further, I should like to refer to a German Messerschmidt patent of 1934 (D.R.P. No. 635,568) for a wing with delayed stalling wing tips, obtained by providing the nose of the aerofoil at the tip with a bigger radius than those in the central part of the wing, in order to secure a different range in the incidences. The underlying idea is apparently based upon the tests described in N.A.C.A. Techn. Note No. 416 (Characteristics of two sharp-nosed airfoils having reduced spinning tendencies, by E. N. Jacobs). I am not aware if this interesting proposal has found any application up to now, but I think it should work well, apart from the problem of aerodynamical efficiency.

Yours, etc.,

A. R. WEYL.

REVIEWS.

Women with Wings.

By Pauline Gower. (John Long, 10/6).

This light-hearted book should have been called " Two Girls in a Plane " and presented as a companion piece to " Three Men in a Boat." It contributes little to our knowledge of aviation, beyond some practical hints for would-be airwomen; but then it has no such pretensions. Its charm lies in a graphic picture of two high-spirited girls who started their partnership with no money and an experience of flying which may be judged from this conversation:—

" Dorothy, the throttle's bust. What shall we do? " Dorothy's voice came back, cheerfully reassuring: " No it isn't, you chump. I've only got a suitcase on it."

From this irresponsible beginning, by dint of sheer pluck and hard work, developed the best woman engineer and the steadiest " joy-riding " pilot in England.

There are moments of drama: the death of a parachutist; Pauline, feeling " small and cold and sick," lost above fog on her first night flight; Dorothy jumping on the wing-tip of a fast-moving plane to avert an accident; but the keynote of the book is an elfin chuckle.

My Life.

By Jean Batten. (Harrap, 8/6).

This book has a twofold appeal. The general public will enjoy the story of a determined young woman who pursued her goal unwaveringly, sacrificing to it, first the piano which was her most cherished possession, and later the marriage that might have hindered her success. To long-distance pilots it will recall vivid memories: Alarm-clocks greeted by " muttering and smothered oaths " from fellow-guests; black coffee spilt in the cockpit of the bumping machine; brief, unstinted hospitality from men and women on the outposts of the Empire.

Future record-breakers should read the book for its valuable details about preparation for flights, customs formalities in various countries; surface conditions of aerodromes and difficulties of approach: Nicosia, " red earth surface . . . difficult to distinguish . . . sparsely covered with shrub "; Victoria Point, " high palm trees . . . a mountain overhung one end "; Theis . . . " only a square in the centre of the big aerodrome had been cleared and the rest was now overgrown."

Jean Batten writes as competently as she flies. " In flying I found the combination of the two things that meant everything to me: the intoxicating drug of speed, and freedom to roam the earth."

About Petroleum.

J. C. Crowther, Oxford University Press, 1938. 7/6 net.

This is a history of the origin of petroleum, its commercial development, and processes of refining. The world-wide use of petroleum and lubricating oils gives the book an appeal to all those users who have the desire to learn a little bit more about petroleum. Written in simple language, *About Petroleum*, nevertheless, covers a wide field, from the finding of the crude oil to hydrogenation processes. The chapters on oil in the earth's crust, and finding oil, are particularly interesting not only on general grounds, but on the particular one that, to quote " Since 1920 much use has been made of the aeroplane in prospecting for

oil." Aerial surveys discovered the Rancherios gas-field in Mexico, and encouraged the prospecting of several promising districts until oil was found. Maps of the surface of districts where oil may exist are made by photography from an aeroplane. These maps reveal details of surface features which could not be collected and recorded without much labour by geologists working on the surface.

The following chapter describes other modern methods of prospecting for oil. The artificial earthquake wave method, which indicates the presence of different strata in the earth's surface by the way the shock-waves are bent, changes in the direction and strength of gravity; variations of the earth's magnetic field, and electrical measurements have all been used to find oil. These methods, which have proved very successful, have the advantage of being much less expensive than boring methods, and further, that by their means, many deposits of oil are being discovered which may not have been tapped if drilling had had to be resorted to. The chapter on drilling methods is a very clear and fascinating description of the difficulties found, and overcome by oil engineers. It will come as a surprise to most people to learn that in the United States alone more than 20,000 new holes are drilled every year, at a total cost of over £100,000,000. Distillation, cracking, hydrogenation and purification are all adequately dealt with in succeeding chapters. The book can be thoroughly recommended.

OVER THE NORTH POLE.

George Baidukov. G. G. Harrap & Co., Ltd., 1938. 5/- net.

This is an account by George Baidukov, one of the three Soviet airmen who took part in the flight from Moscow to Portland, U.S.A., a distance of 5,507 miles, in June, 1937.

The story is told in sober language. The flight began at 1 p.m. on June 18th, 1937, and ended in the middle afternoon of June 20th. It is a narrative of strenuous flying, of endurance, and of great difficulties. The book would have been more valuable as a record, however, if the author had given in it, full and authoritative particulars of the A.N.T. 25, of the kind which would allow its performance to be judged more critically.

HANDBOOK OF AERONAUTICS. Volume III.

Published by Sir Isaac Pitman and Sons, Ltd. Price 20s.

This volume of the handbook is concerned with design data and formulæ for aircraft and airscrews, the aircraft section being written by Captain Laurence Pritchard, Hon. F.R.Ae.S., and the airscrew section by Mr. C. N. H. Lock, F.R.Ae.S. There is also a section devoted to general tables and conversion factors.

The aircraft section deals with the standard methods of assessing the loads on aircraft and the methods of stressing them when these loads have been ascertained. It is largely based on Air Ministry publications on this subject, but reference is made in a number of instances to published papers which deal specifically with particular problems. The whole field is dealt with adequately and capably, the only omission noted is that there is no reference to loads caused by wing engines.

Those engaged in aircraft stressing will find this book invaluable. Information scattered over many Air Ministry publications and in papers published in aeronautical journals, many of which are of foreign origin, are brought together in a form which is extremely convenient for reference, and it is hardly necessary to say that it is right up to date.

The airscrew section is a very useful résumé of modern methods of designing and stressing airscrews, special emphasis being laid on the use of graphs, of which a number are provided in a pocket at the end of the book. Again, the information given is well arranged and up to date.

It should be said that both sections are supplied with an adequate bibliography and that the indexing is a great improvement on previous editions.

There is a useful collection of general tables, but in certain cases, notably on page 208, there is evidence of inadequate proof reading. In modern handbooks tables dealing with altitude should be carried to a higher altitude than 25,000 feet. In the first section 60,000 feet is the limit used and this example should be copied. Also, there is no reason why a table in an English book should give densities of liquids in O.S. gallons, as is done on page 209.

JOACHIM BITTNER: "TAFELN FUER DEN FLUGZEUGBAU" (Tables for Aeroplane Construction). Compiled with the aid of members of the German Aeronautical Standards Committee (Falu). Berlin, 1937. With amendments. Published by C. J. E. Volckmann Nachf. E. Wette. Appr. 290 tables, diagrams and sketches, printed on detachable sheets and assembled in a file of pocket book size. Price R.M. 6.40.

This valuable and practical work contains tables and diagrams relating to design, manufacture and service and also general physical and mechanical data. Figures for the strength of aircraft materials, for a number of standard components (including airscrews, undercarriage legs, pipe connections, etc.), weight data and dimension figures, falu standards, data for the workshop handling of certain materials and other useful information are given in the convenient form of data sheets. Tables of a similar handy arrangement would be much appreciated by everybody compelled frequently to extract information from the present Handbook of Aeronautics.

Since these data sheets are kept in a "spring-back" file, a selection and an exchange of superseded tables is easily possible, thus facilitating corrections and amendments which the rapid progress of aeronautical engineering requires.

K. ANDERS AND H. EICHELBAUM: "WOERTERBUCH DES FLUGWESENS" (Aeronautical Glossary). Leipzig, 1937. Published by Verlag von Quelle and Mayer. 203 pp. with 468 fig. Price R.M. 5.

A modern glossary of aeronautical terms, generally, intended exclusively for instructional purposes and illustrated in a lavish manner. The book is up to date and includes descriptions of engine, aeroplane and sailplane types, qualifications of well known aeronautical people, etc. A number of pictures is reproduced from English aeronautical magazines.

Aeronautical slang expressions from the side of practical flying are to a certain extent included, but the most popular and instructive terms of the pilots' appear to be omitted. As this glossary is compiled for and from German aeronautics, and as it should neither be considered as a pure technical nor scientific effort, a number of definitions given need rectification from a technical or historical viewpoint, and its direct value for this country is but small.

BRUNO ECK: "VENTILATOREN" (Ventilators). Design and Service of Centrifugal and Windmill Blowers. Published by Verlag Julius Springer. Berlin, 1937. 197 pp. with 192 fig. Price R.M. 12.

The author, a well known expert in engineering aerodynamics, gives in this work an excellent treatise of the aerodynamical design of ventilating blowers. The detail design and the structural problems involved are intentionally neglected because they are assumed to be of a simple nature and less interesting for a designer seeking information. From an aerodynamical aspect, the author has certainly succeeded in compiling first class and really up-to-date information for engineers interested in the theoretical fundamentals and practical applications of blower design. For the designer, therefore, this book should be valuable. English publications and designs are fully taken into account. A final chapter deals with the constructive side, giving samples of well known ventilator types.

H. G. SCHULZE AND W. STIASNY: "FLUG DURCH MUSKELKRAFT" (Muscle Power Flight). Frankfurt a.M., 1937. Published by "Naturkunde und Technik," Verlag Fritz Knapp. 223 pp. with numerous sketches and photogr. tables. Price R.M. 5.50.

Flying by means of muscle power has in recent years come more into the limelight, and the serious engineering efforts undertaken in Germany and Italy certainly justify a book of this sort describing in a reliable and unprejudiced manner nearly all attempts so far made to solve a problem which scientists have pronounced insoluble.

The authors begin with the earliest attempts known and give an interesting, critical and fairly complete record of the development work accomplished up to the recent efforts of Haessler-Villinger and Dr. M. Sultan in Germany. Even for the modern aeronautical engineer who does not take any interest in muscle power flight it will certainly be most fascinating to follow this account of invention, engineering progress and tragic disappointment.

The theoretical aspect is intentionally neglected, and a further edition might gain in value if the abridged chapters dealing with theory would be enlarged for a real technical study of the intricate problems concerned. A very valuable bibliography is added.

METAL AIRCRAFT FOR THE MECHANIC.

By J. Healey. Published by Sir Isaac Pitman and Sons, Ltd. Price 5s.

This book is the latest addition to Pitman's Aeronautical Engineering Series, and the author is an examiner of the Trade Test Board, Royal Air Force. The book itself deals with the work which an aircraft mechanic may have to perform on metal aircraft, and the subject matter includes the reading of blue prints, the making of fittings by hand, marking out, notes on methods of repairing metal structures, and various incidental matters.

Books of this type, issued at a cheap price, are beyond question of value to a man who is in process of learning his job, and if, as in this case, they contain information as to the best way of carrying out unusual jobs, they are useful as reference books to men of experience. There is perhaps a risk that the novice may think that knowing how a job should be done may in some measure take the place of skill. Skill can only come from practice and those who have never handled tools will find difficulty in following the instructions and methods described here.

Generally it can be said that the book performs its function very satisfactorily and that it should be a very useful help to those for whose use it is intended. It would be more useful still if an index had been included.

THE CLOUDS REMEMBER.

By Leonard Bridgeman. Published by Gale and Polden, Ltd. Price 10s. 6d.

This book contains some forty drawings by Mr. Bridgeman of well-known wartime aeroplanes, both English and French, which are accompanied by a so-called commentary by Major Oliver Stewart, this being the reading matter of the book.

Normally, one would describe it as written by Major Stewart and illustrated by Mr. Bridgeman, and it is difficult to imagine a team better qualified to write and illustrate a book of this type.

Mr. Bridgeman's drawings of aeroplanes are well known everywhere. Not only has he the skill to make his aeroplanes come to life in his pictures, but he is gifted with an uncanny accuracy of draughtsmanship which must be backed by a considerable amount of research. On many occasions I have suspected Mr. Bridgeman to have committed some error, but on looking the matter up I have found him to be right. It is sufficient to say that the drawings in this book are up to his usual high standard.

It is pleasing to note that Major Stewart can still find time to write on aeronautical subjects. It was generally felt to be a great loss to aeronautical journalism when he left it to deal with terrestrial matters. As a wartime pilot he is at his best in this book. Not only has he flown many of the machines he describes, but he knows what they did in the war, what other pilots thought of them, and all their peculiarities and vices. All of this information he sets before the reader in a pleasant style, and one feels that many of them were old friends of his whose virtues deserve to be recorded for the benefit of posterity.

He is right in emphasising that these machines belong to an obsolete school of design and, as this school is never likely to come into fashion again, it is interesting and useful to be told what they were like to fly and how they were controlled. Those who flew in the war will find this book of peculiar interest, but it ought also to be read by the younger generation who will learn much about the sort of aeroplanes in which their fathers went to war.